Bull. Spec. Astrophys. Obs., 2000, 49, 14-19

BVR_cI_c photometry of the host galaxies of GRB 980703 and GRB 990123

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Received February 10, 2000; accepted April 26, 2000.

Abstract. We present a photometry of the host galaxies of GRB 980703 and GRB 990123 which was performed about 20 days and a half year after the gamma-ray bursts occurred, respectively. The contributions of the optical transients (OT) were negligible in both cases. We derived broad-band BVR_cI_c spectra of the host galaxies and compared them to continuum spectra of different Hubble-type galaxies and averaged spectra of starburst galaxies. For $H_0 = 60$ km s^{-1} Mpc^{-1} and three Friedmann cosmological models with matter density and cosmological constant parameters $(\Omega_m,\Omega_\Lambda) = (1,0),(0,0),\ (0,1)$ we estimated $M_{B_{rest}}$ and star formation rates (SFRs) using the fluxes in photometric bands for the host galaxies. Within the range of cosmological parameters our estimates of the absolute magnitudes are: $M_{B_{rest}} = -20.60 \div -21.73$ for the GRB 980703 host galaxy and $M_{B_{rest}} = -20.20 \div -21.82$ for the GRB 990123 host galaxy. We obtained estimates of K-correction values and absolute magnitudes of the host galaxies using SEDs (spectral energy distribution) for star-forming galaxies.

Key words: gamma-rays: bursts: cosmology: observations – photometry: individual (GRB 980703, GRB 990123): galaxy – starbursts

1. Introduction

The origin of cosmic γ-ray bursts (GRBs) is still one of the outstanding problems in modern astronomy. Recently the study of GRBs has been revolutionized by the discovery of X-ray (Costa et al., 1997), optical (van Paradijs et al., 1997) and radio transients (Frail et al., 1997). The follow-up of optical transients (OT) resulted in the majority not only with OTs' light curves but also their redshift measurements and the detection of GRB hosts. By now about 15 optical afterglows have been detected, almost all within a fraction of an arc second of very faint galaxies, with typical R-band magnitudes of 22–26 and over. About 10 redshifts have been measured in the range from $z = 0.6$ to $z = 3.4$. The long duration GRBs appear to be associated with star forming regions in the galaxies. The studies of the host galaxies and their properties advance understanding of the nature of the progenitor systems. In some proposed models association of bursts with explosions of massive stars becomes popular (see ref. Paczyński, 1999; MacFadyen & Woosley, 1999, and references therein).

Here we report the results of our BVR_cI_c observations of the optical counterpart of GRB 980703 which were carried out after those of Bloom et al. (1998). The latest observations of this object were obtained in the infrared JHK bands by Bloom et al. (1998). In the case of the host galaxy of GRB 990123 our BVR_cI_c observations are the latest. In this paper we compare the BVR_cI_c spectra of the host galaxies of GRB 980703 and GRB 990123 with spectral energy distributions of normal galaxies of different Hubble types and extend the comparison to averaged spectra (SEDs) of S1 and S2 star-forming galaxies (Connoly et al., 1995). We made estimates of K-correction values and absolute magnitudes of the host galaxies using spectra of normal Hubble-type galaxies and SEDs for star-forming galaxies. Rough estimates of the lower limits of star formation rates (SFR) in the host galaxies of GRB 980703 and GRB 990123 were derived using the continuum luminosity at $\lambda = 2800$ Å by extrapolating for the host galaxy of GRB 990123 between R_c and I_c bands and from the value of the flux in the V band for the host galaxy of GRB 980703.

2. Observations and data reduction

Observations of the host galaxies of GRB 980703 and GRB 990123 were performed using the primary focus CCD photometer of the 6 m telescope of SAO RAS. They were carried out with the standard (Johnson-Kron-Cousins) photometric BVR_cI_c system. The direct BVR_cI_c images for the host galaxy of GRB 980703 are available

Table 1: *Photometry of the host galaxies of GRB 980703 and GRB 990123*

Host	Date UT	Band	Exp. (s)	Magnitude, obs.^{a}	Seeing
GRB 980703	24.05 Jul. 1998	B	480	23.40 ± 0.12	$1''.3$
	24.06 Jul.	V	320	22.85 ± 0.10	$1''.2$
	24.06 Jul.	R_c	300	22.44 ± 0.08	$1''.2$
	24.07 Jul.	I_c	360	22.26 ± 0.18	$1''.2$
GRB 990123	8.85 Jul.	B	600	24.90 ± 0.16	$1''.5$
	8.86 Jul.	V	600	24.47 ± 0.13	$1''.3$
	8.84 Jul. 1999	R_c	600	24.47 ± 0.14	$1''.1$
	8.87 Jul.	I_c	600	24.06 ± 0.3	$1''.3$

$^a BVR_cI_c$ magnitudes are uncorrected for Galactic extinction.

at `http://www.sao.ru/~sokolov/GRB/980703.html`. Table 1 presents the summary of observations, where the magnitudes are uncorrected for Galactic extinction. [1].

We performed photometric calibrations using the Landolt standard fields (Landolt, 1992): PG1633, PG1657, PG2331, PG2336 for the host galaxy of GRB 980703, and PG2213, SA110 for the host galaxy of GRB 990123. To estimate the Milky Way reddenning for the host galaxy of GRB 980703, we used extinction values from Cardelli et al. (1989). We derived $0\overset{m}{.}251$, $0\overset{m}{.}188$, $0\overset{m}{.}141$ and $0\overset{m}{.}090$ in our photometric bands BVR_cI_c, respectively. Our BVR_cI_c observations of the optical counterpart of GRB 980703 were carried out after those of Bloom et al. (1998) on July 18, 1998. The most recent observations of this object were made by Bloom et al. (1998) in the infrared JHK bands on August 7, 1998. In the case of the host galaxy of GRB 990123 our BVR_cI_c observations are the latest. We consider that the continuum was expected with minimum change due to the fading of the OT.

3. Cosmological models

The estimate of intrinsic physical parameters of extragalactic objects with redshifts approaching 1 depends considerably on the adopted cosmological model. The standard Friedmann model contains three parameters: Hubble constant H_0, matter density parameter Ω_m, and cosmological constant parameter Ω_Λ. Recent studies of the Hubble constant put it within the range $50 - 70 \mathrm{km s}^{-1}$ Mpc^{-1} (see Theureau et al., 1997). In this paper we adopt $H_0 = 60$ km s^{-1} Mpc^{-1} . The values of Ω_m and Ω_Λ are observationally less constrained. The recent work on the $m - z$ test with supernovae of type Ia at redshifts up to 1 by Garnavich et al. (1998) makes it imperative to consider also an empty universe with a cosmological constant in addition to the standard inflationary model. For a review of modern cosmological models and the necessary mathematical relations, see Baryshev et al. (1994). Here we use three Friedmann models which conveniently limit reasonable possibilities:

$$H_0 = 60 \text{ km s}^{-1} \text{ Mpc}^{-1},\ \Omega_m = 1,\ \Omega_\Lambda = 0 \quad (A)$$

$$H_0 = 60 \text{ km s}^{-1} \text{ Mpc}^{-1},\ \Omega_m = 0,\ \Omega_\Lambda = 0 \quad (B)$$

$$H_0 = 60 \text{ km s}^{-1} \text{ Mpc}^{-1},\ \Omega_m = 0,\ \Omega_\Lambda = 1 \quad (C).$$

For these models the relation $\Omega_m + \Omega_\Lambda + \Omega_k = 1$ is valid, where $\Omega_m = \rho_0 8\pi G / 3H_0^2$, $\Omega_\Lambda = \Lambda c^2 / 3H_0^2$, and $\Omega_k = -kc^2 / R_0^2 H_0^2$. Here ρ, Λ, k, and R are the density, cosmological constant, curvature constant, and radius of curvature, respectively, and "0" denotes the present epoch.

The luminosity distance R_{lum}, the angular size distance R_{ang} and the proper metric distance R_p are related as:

$$R_{lum} = R_{ang}(1+z)^2 = R_p(1+z), \tag{1}$$

where the proper distances for the adopted models are given by

$$R_p = \begin{cases} R_H \frac{2(z - \sqrt{1+z} + 1)}{1+z} & \text{for model A,} \\ R_H \frac{z(1+0.5z)}{1+z} & \text{for model B,} \\ R_H\, z & \text{for model C.} \end{cases} \tag{2}$$

Here $R_H = c/H_0$ is the present value of the Hubble radius.

The absolute magnitude $M_{(i)}$ of the source observed in filter (i) can be calculated from the magnitude – redshift relation

$$M_{(i)} = m_{(i)} - K_{(i)}(z) - 5 \log(R_{lum}/\mathrm{Mpc}) - 25, \tag{3}$$

where $m_{(i)}$ is the observed magnitude of the object in the photometric band system (i), and $K_{(i)}(z)$ is the

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[1] This paper gives more accurate BVR_cI_c values with the UT dates (corresponding to Table 1) of observations for the host galaxy of GRB 980703 unlike the preliminary BVR_cI_c values given in GCN notice #147.

K-correction at redshift z, calculated from the rest-frame spectral energy distribution.

The linear size l of an object having an angular size θ is given by

$$l = \theta R_{ang} = \theta R_p/(1+z). \tag{4}$$

The K-correction in Eq. (3) can be calculated from the standard formula (Oke & Sandage, 1968):

$$\begin{aligned} K_{(i)}(z) &= 2.5\log(1+z) + \\ &+ 2.5\log\frac{\int_0^\infty F_\lambda S_{(i)}(\lambda)\mathrm{d}\lambda}{\int_0^\infty F_{\lambda/(1+z)} S_{(i)}(\lambda)\mathrm{d}\lambda}. \end{aligned} \tag{5}$$

In this formula F_λ is the rest-frame spectral energy distribution, $S_{(i)}$ is the sensitivity function for the filter (i). For our photometric system we used the sensitivity functions for BVR_cI_c filters from Bessel (1990).

4. Estimation of the K-corrections

The first spectral observations of the OT of GRB 980703 were obtained with the Keck-II 10 m telescope on UT 1998 July 07.6 and 19.6 (Djorgovski et al., 1998). Several strong emission lines were detected. These were [OII], Hδ, Hγ, Hβ and [OIII] with a redshift $z = 0.9662 \pm 0.0002$. In addition, in the blue part of the spectrum some absorption features (FeII and MgII, MgI absorption systems) with $z = 0.9656 \pm 0.0006$ were detected. In the case of the OT of GRB 990123 absorption lines were detected only (Kelson et al., 1999, Hjorth et al., 1999) with $z_{abs} = 1.6004$. The HST image reveals that the optical transient is offset by 0.″67 from an extended object (Bloom et al., 1999). This object is most likely to be a host galaxy of GRB 990123 and a source of the absorption lines of metals at the redshift $z = 1.6004$.

In Fig. 1 we compare the BVR_cI_c broad-band spectra of the host galaxies of GRB 980703 and GRB 990123 with the spectral energy distributions of normal galaxies of different Hubble types (Pence, 1976). Table 2 presents fluxes of the host galaxies. For our photometric bands we used the zero-points from Fukugita et al. (1995). Fluxes of the host galaxy of GRB 980703 are presented according to dereddened magnitudes. Within our magnitude errors Galactic reddening for the host galaxy of GRB 990123 is negligible. The central $\lambda_{obs} = \lambda_{eff}$ for our photometric system are equal correspondingly to: $\lambda_B = 4448$ Å, $\lambda_V = 5505$ Å, $\lambda_R = 6588$ Å and $\lambda_I = 8060$ Å, FWHM are equal to $\Delta\lambda_B = 1008$ Å, $\Delta\lambda_V = 827$ Å, $\Delta\lambda_R = 1568$ Å, $\Delta\lambda_I = 1542$ Å, respectively.

Using equation 5 and the spectral energy distribution of the Im Hubble-type galaxies, we estimated the value of the K-correction for the magnitudes of the host galaxies of GRB 980703 and GRB 990123 according to $z = 0.966$ and $z = 1.6$, respectively. The estimated values of the K-correction in the B band are $K_B = 0.68$ for the host galaxy of GRB 980703 and $K_B = 0.88$ for the host galaxy of GRB 990123. In this case, the absolute magnitudes from equation 3 for the host galaxy of GRB 980703 are: $M_{B_{rest}} = -21.29$ for model (A), $M_{B_{rest}} = -21.81$ for model (B) and $M_{B_{rest}} = -22.42$ for model (C). For the host galaxy of GRB 990123 in the same way absolute magnitudes are $M_{B_{rest}} = -20.95$ for model (A), $M_{B_{rest}} = -21.77$ for model (B) and $M_{B_{rest}} = -22.57$ for model (C).

However, we consider it to be not quite correct to compare our broad-band spectra to ones of normal Hubble type galaxies. Obviously the starburst activity may drastically change the spectral distribution towards the ultraviolet part of the spectrum. According to this consideration, we compared our BVR_cI_c spectra to the averaged spectral energy distribution of starburst galaxies from Connoly et al. (1995). Figs. 2 and 3 demostrate a comparison of the starburst averaged spectral energy distributions with the BVR_cI_c broad-band spectra of the host galaxies of GRB 980703 and GRB 990123, respectively. The spectra of starburst were groupped according to increasing values of the colour excess $E(B-V)$: from S1, with $E(B-V) = 0.05$ to S6, with $E(B-V) = 0.7$ (Connoly et al., 1995). Using the relation for τ_B^l (Balmer optical depth) from Calzetti et al. (1994), we derived the values of colour excess for individual starburst galaxies. They are $E(B-V) < 0.10$ for S1, $0.11 < E(B-V) < 0.21$ for S2, $0.25 < E(B-V) < 0.35$ for S3, $0.39 < E(B-V) < 0.50$ for S4, $0.51 < E(B-V) < 0.60$ for S5 and $0.61 < E(B-V) < 0.70$ for S6 (see Table 3 in Calzetti et al., 1994). In Fig. 2 and Fig. 3 the spectra of the S1 and S2 type galaxies were averaged with a 10 Å window.

In this case, the calculations of the K-corrections from equation 5 yield $K_B = -0.01$ for the host galaxy of GRB 980703 and $K_B = 0.13$ for the host galaxy of GRB 990123. Then, the absolute magnitudes for the host galaxy of GRB 980703 are $M_{B_{rest}} = -20.60$ for model (A), $M_{B_{rest}} = -21.12$ for model (B) and $M_{B_{rest}} = -21.73$ for model (C). For the host of GRB 990123 M_B are: $M_{B_{rest}} = -20.20$ for model (A), $M_{B_{rest}} = -21.02$ for model (B) and $M_{B_{rest}} = -21.82$ for model (C).

5. Estimations of star formation rate

We have roughly estimated also SFR using the continuum luminosity at $\lambda_{rest} = 2800$ Å (see Madau et al., 1998). In the calculations we assumed the cosmological models described above.

For the host galaxy of GRB 980703 the effective wavelength of the V band for $z = 0.966$ corresponds to 2800 Å in the rest frame. Using the flux in the V band we estimated SFR for the host

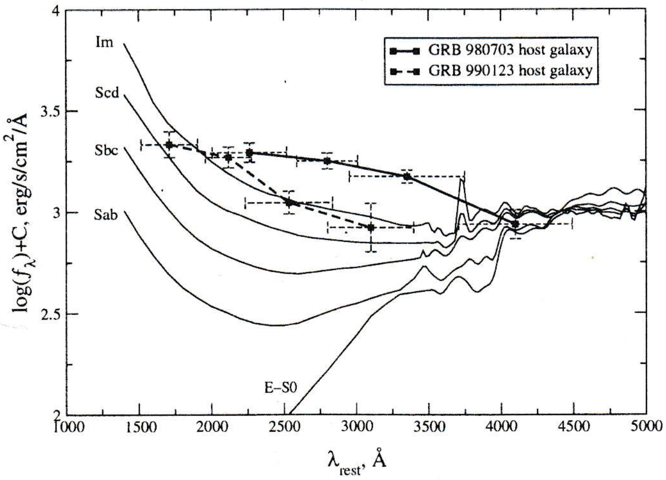

Figure 1: *A comparison of the host galaxy of GRB 980703 and GRB 990123 broad-band rest-frame ($z = 0.966$ and $z = 1.6004$, respectively) spectra $\log F_\lambda = \log F_{\lambda,obs} + C$ with averaged continuum spectra of galaxies of different Hubble types. The spectra were shifted by some arbitrary constants for the best fits. FWHM of each filter for λ_{eff} with the account for z are denoted by dashed horizontal lines with bars.*

Table 2: *Fluxes of the host galaxies*

Host	Band	$\log Flux_{\lambda,obs}$ $\frac{erg}{s\cdot cm^2 Å}$	$\log Flux_{\nu,obs}$ $\frac{erg}{s\cdot cm^2 Hz}$
GRB 980703	B	-17.468 ± 0.048	-28.656 ± 0.048
	V	-17.508 ± 0.040	-28.509 ± 0.040
	R_c	-17.588 ± 0.032	-28.440 ± 0.032
	I_c	-17.823 ± 0.072	-28.483 ± 0.072
GRB 990123	B	-18.168 ± 0.064	-29.356 ± 0.064
	V	-18.231 ± 0.052	-29.233 ± 0.052
	R_c	-18.456 ± 0.056	-29.308 ± 0.056
	I_c	-18.579 ± 0.120	-29.247 ± 0.120

galaxy of GRB 980703: $SFR_{Salpeter} \approx 15 \pm 2 M_\odot$ yr^{-1}, $SFR_{Scalo} \approx 23 \pm 2\ M_\odot$ yr^{-1} for model (A); $SFR_{Salpeter} \approx 24 \pm 2\ M_\odot$ yr^{-1}, $SFR_{Scalo} \approx 37 \pm 4\ M_\odot$ yr^{-1} for model (B); $SFR_{Salpeter} \approx 43 \pm 4\ M_\odot$ yr^{-1}, $SFR_{Scalo} \approx 66 \pm 6\ M_\odot$ yr^{-1} for model (C), where the index of Salpeter and Scalo denotes the Salpeter and Scalo initial mass function (IMF) (Madau et al., 1998).

To estimate SFR of the host galaxy of GRB 990123, we used the interpolated value of the flux at the wavelength 2800 Å in the rest frame between the R_c and I_c band. We assumed

$$\log F_{\nu,2800Å} = -29.28 \pm 0.13\ \frac{erg}{s \cdot cm^2 Hz}\ .$$

The calculation yields: $SFR_{Salpeter} \approx 8 \pm 2\ M_\odot$ yr^{-1}, $SFR_{Scalo} \approx 12 \pm 4\ M_\odot$ yr^{-1} for model (A); $SFR_{Salpeter} \approx 17 \pm 6\ M_\odot$ yr^{-1}, $SFR_{Scalo} \approx 25 \pm 9\ M_\odot$ yr^{-1} for model (B); $SFR_{Salpeter} \approx 34 \pm 12\ M_\odot$ yr^{-1}, $SFR_{Scalo} \approx 54 \pm 17\ M_\odot$ yr^{-1} for model (C).

Of course, these estimates are the lower limit to SFR because our calculations were performed without any galaxy rest-frame extinction correction. Moreover, uncertainties of our results are estimated formally from the errors of fluxes.

6. Discussion

Observations were carried out a significant time after the gamma-ray bursts. For the host galaxy of GRB 980703 it was about 20 days after the gamma-ray burst, and for the host galaxy of GRB 990123 about a half year. This allows us to consider that the contribution of the optical transient is very small and we observed light only of the host galaxies.

As a discussion, it should be noted that there are uncertainties in the estimates of the absolute magnitudes of the host galaxies due to the K-correction. In the case of the host galaxy of GRB 990123 this uncertainty is about 1^m, and in

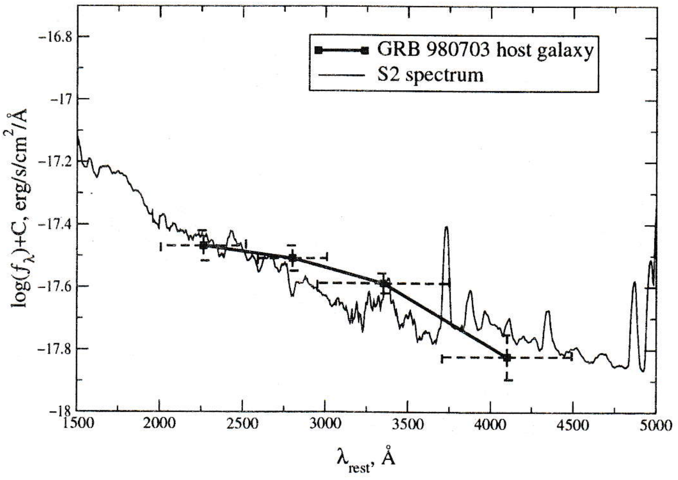

Figure 2: *A comparison of the host galaxy of GRB 980703 broad band rest-frame* ($z = 0.966$) *spectrum to spectrum of S2-galaxies,* $\log F_\lambda = \log F_{\lambda,S2} + C$ *(see Connoly et al., 1995). FWHM of each filter for* λ_{eff} *with the account for* z *are denoted by dashed horizontal lines with bars.*

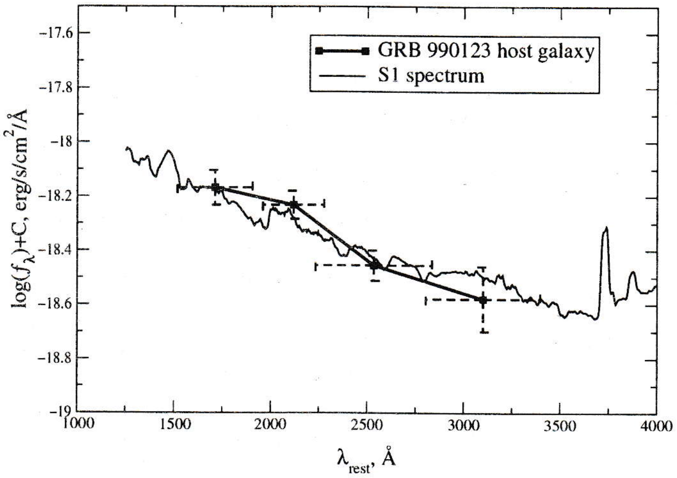

Figure 3: *A comparison of the host galaxy of GRB 990123 broad band rest-frame* ($z = 1.6$) *spectrum to spectrum of S1-galaxies,* $\log F_\lambda = \log F_{\lambda,S1} + C$ *(see Connoly et al., 1995). FWHM of each filter for* λ_{eff} *with the account for* z *are denoted by dashed horizontal lines with bars.*

the case of the host of GRB 980703 it is about $0^m\!.7$. However, we consider that a more correct result is the value of M_B according to the comparison with the starburst averaged spectra — $M_{Brest} = -20.60, -21.12, -21.73$ for the host galaxy of GRB 980703 in (A), (B), (C) cosmological models, respectively, and $M_{Brest} = -20.20, -21.02, -21.82$ for the host galaxy of GRB 990123. Moreover, our BVR_cI_c broad-band spectra are better fitted by the S1 and S2 spectral energy distribution. To compare our results to the results of Bloom et al. (1998, 1999) we assume a cosmology model with $H_0 = 65$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.2$ and $\Omega_\Lambda = 0$. For the host galaxy of GRB 980703 we used the value of the luminosity distance from Bloom et al. (1998), $d_L = 1.92 \times 10^{28}$ cm. In the case of the host galaxy of GRB 990123 we used the value of the luminosity distance from Bloom et al. (1999), $d_L = 3.7 \times 10^{28}$ cm. Calculations from equation 3 yield: $M_{B_{rest}} = -20.8$ and $M_{B_{rest}} = -20.62$ for the host galaxies of GRB 980703 and GRB 990123, respectively, while the values of Bloom et al. (1998, 1999) are -20.2 and -20.0 for the host galaxies of GRB 980703 and GRB 990123, respectively. Note that the estimates of absolute magnitudes of Bloom et al. (1998, 1999) for the both host galaxies are performed in a different way without the K-correction by fitting to the spectrum in the case of the host galaxy GRB 980703 and by interpolating between the observed STIS and the K-band data points using a power law in the case of the host galaxy of GRB 990123.

It should be noted that our estimates of the star formation rate are higher than the estimates of Djorgovski et al. (1998) and Bloom et al. (1999). It is interesting that for the host galaxy of GRB 980703 our flux at $\lambda = 2800\,\text{Å}$ is $\approx 3.1\ \mu$Jy and is matching the value of the flux on July 7 from Djorgovski et al. (1998). Probably, the OT contribution was already negligible in the V band on July 7. In the case of the host galaxy of GRB 990123 our value of the flux at $\lambda = 2800\,\text{Å}$ was estimated by interpolation between observed points. However, the values of Bloom et al. (1999) are 0.17 μJy (for $\beta = 0$) and 0.21 μJy (for $\beta = -0.8$), while ours are $0.52^{+0.18}_{-0.14}\mu$Jy. This discrepancy can be explained as follows. Our estimate of the flux was performed by interpolation between the R_c ($\lambda_{eff} = 6588\,\text{Å}$) and I_c ($\lambda_{eff} = 8060\,\text{Å}$) bands, while the values of Bloom et al. (1999) were interpolated with the power law between STIS (approximately V band, $\lambda_{eff} = 5505\,\text{Å}$) point and K band ($\lambda_{eff} = 2.195\mu$m). Moreover, Bloom et al. (1999) measured the flux of the host galaxy by masking sets of pixels dominated by the OT because observations in the K band were carried out on 9 and 10 Febrary, 1999, 17–18 days after the gamma-ray burst when contribution of the OT was not negligible, while our observations were performed about a half year after the gamma-ray burst occurred. Obviously, our estimate is more accurate than that of Bloom et al. (1999).

Acknowledgements. We thank S.V. Zharikov for assistance in observations, and T.N. Sokolova for help in the work with the text. This work has been partly supported by the "Astronomy" Programme (grant 97/1.2.6.4), INTAS N 96-0315 and RFBR N98-02-16542.

References

Baryshev Yu.V., Sylos Labini F., Montuori M., Pietronero L., 1994, Vist. Astron., **38**, 419

Bessel M.S., 1990, Publ. Astr. Soc. Pacific, **102**, 1181

Bloom J.S., Frail D.A., Kulkarni S.R., Djorgovski S.G., Halpern J.P., Marzke R.O., Patton D.R., Oke J.B., Horne K.D., Gomer R., Goodrich R., Campbell R., Moriarty-Schieven G.H., Redman R.O., Feldman P.A., Costa E., 1998, Astrophys. J., **508**, L21

Bloom J.S., Odewahn S.C., Djorgovski S.G., Kulkarni S.R., Harrison F.A., Koresko C., Neugebauer G., Armus L., Frail D.A., Gal R.R., Sari R., Squires G., Illingworth G., Kelson D., Chaffee F.H., Goodrich R., Feroci M., Costa E., Piro L., Frontera F., Mao S., Akerlof C., McKay T.A., 1999, Astrophys. J., **518**, L1-L4

Calzetti D., Kinney A.L., Storchi-Bergmann T., 1994, Astrophys. J., **429**, 582

Cardelli J.A., Clayton G.C., Mathis J.S., 1989, Astrophys. J., **345**, 245

Connoly A.J., Szalay A.S., Bershady M.A., Kinney A.L., Calzetti D., 1995, Astron. J., **110**, 1071

Costa E., Frontera F., Heiss J. et al., 1997, Nature, **387**, 783

Djorgovski S.G., Kulkarni S.R., Bloom J.S., Goodrich R., Frail D.A., Piro L., Palazzi E., 1998, Astrophys. J., **508**, L17

Frail D.A., Kulkarni S.R., Nicastro L., Feroci M., Taylor G.B., 1997, Nature, **386**, 261

Fukugita M., Shimasaku K., Ichikawa T., 1995, Publ. Astr. Soc. Pacific, **107**, 945

Garnavich P.M., Kirshner R.P., Challis P., et al., 1998, Astrophys. J., **493**, L53

Hjorth J., Andersen M.I., Cairos L.M., et al., 1999, GCN Circ., 219

Kelson D.D., Illingworth G.D., Franx M., Magee D., van Dokkum P.G., 1999, IAU Circ., 7096

Landolt A.U., 1992, Astron. J., **104**, 340

Madau P., Pozzetti L., Dickinson M., 1998, Astrophys. J., **498**, 106

MacFadyen A., Woosley S.E., 1999, astro-ph/9810274, http://xxx.lang.gov

Oke J.B., Sandage A., 1968, Astrophys. J., **154**, 21

Paczyński B., 1999, astro-ph/9909048, http://xxx.lanl.gov

Pence W., 1976, Astron. J., **203**, 39

Theureau G., Hanski M., Ekholm T., Bottinelli L., Gouguenheim L., Paturel G., Teerikorpi P., 1997, Astron. Astrophys., **322**, 730

van Paradijs J., Groot P.J., Galama T., et al., 1997, Nature, **386**, 686