GRB 060121: IMPLICATIONS OF A SHORT-INTERMEDIATE-DURATION $\gamma$-RAY BURST AT HIGH REDSHIFT

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ABSTRACT

Since the discovery of the first short-population $\gamma$-ray burst (GRB) afterglows in 2005, the handful of observed events have been found to be embedded in nearby ($z < 1$), bright underlying galaxies. We present multiwavelength observations of GRB 060121, the first short burst observed to clearly outshine its host galaxy (by a factor $>10^3$). A photometric redshift for this event places the progenitor at a most probable redshift of $z = 4.6$, with a less probable scenario of $z = 1.7$. In either case, GRB 060121 could be the farthest short-population GRB detected to date and implies an isotropic-equivalent energy release in gamma rays comparable to that seen in long-population bursts. We discuss the implications of the released energy on the nature of the progenitor. These results suggest that GRB 060121 may belong to a family of energetic short-population events, lying at $z > 1$ and whose optical afterglows would outshine their host galaxies, unlike the first short GRBs observed in 2005. The possibility of GRB 060121 being an intermediate-duration burst is also discussed.

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1. INTRODUCTION

Since 1993 $\gamma$-ray bursts (GRBs) have been classified into two subgroups according to the observed duration and hardness ratio derived from their gamma-ray spectra: short-hard and long-soft events (Kouveliotou et al. 1993). Recent studies have shown that there may be no difference in the hardness distribution between the two (Sakamoto et al. 2006), so we will refer to them as short-population bursts (SPBs) and long-population bursts (LPBs).

The detection of the first X-ray afterglows (Gehrels et al. 2005; Fox et al. 2005; Barthelmy et al. 2005)—and particularly the first optical afterglows (Hjorth et al. 2005; Fox et al. 2005; Covino et al. 2006; Berger et al. 2005a) of SPBs—led to the identification of the probable host galaxy of GRB 050509b (Gehrels et al. 2005) and the secure identification of the host galaxies of GRB 050709 (Villasenor et al. 2005) and GRB 050724 (Barthelmy et al. 2005), and therefore the redshifts of these bursts. These results suggest that SPBs release less energy than do LPBs (Fox et al. 2005; Soderberg et al. 2006)—$\dot{E}_\gamma(\text{SPB} \sim 10^{50}\text{ ergs})$ vs. $\dot{E}_\gamma(\text{LPB} \sim 10^{51}\text{ ergs})$—and that they may originate from the merger of neutron star–neutron star (NS–NS) or neutron star–black hole (NS–BH) binaries at cosmological distances.

Until GRB 060121, the detected optical afterglows of SPBs have been comparable in brightness to their host galaxies or dimmer, unlike the case of LPBs that may outshine their hosts by a factor of up to $\sim 10^5$ (van Paradijs et al. 2000). The distance scale is also considered to be different, having all short bursts with definite redshifts $z_{\text{SPB}} < 0.6$,16 while long bursts show a broader range, mainly between 0.5 and 5, with a mean redshift $\langle z_{\text{LPB}} \rangle \sim 2.8$ (Jakobsson et al. 2006; Berger et al. 2005b).

2. OBSERVATIONS AND DATA REDUCTION

GRB 060121 was detected at 22:24:54.50 UT on 2006 January 21 using the French Gamma Telescope (FREGATE), the wide-field X-ray monitor (WXM), and the soft X-ray camera (SXC) aboard the High Energy Transient Explorer 2 (HETE-2; Arimoto et al. 2006). The position of the gamma-ray event was distributed using the GRB Coordinates Network (GCN) 13 s later. The spectral peak energy $E_p = 120 \pm 7$ keV (Boer et al. 2006), together with a duration of 1.97 $\pm 0.06$ s initially classified it in the SPB group of events. It was also observed by Konus/Wind (Golenetskii et al. 2006a) and followed up by Swift/X-ray Telescope (XRT; Mangano et al. 2006), whose observations substantially improved the initial 28′′ $\text{HETE-2}$ error box radius and helped us to identify the optical counterpart (Malesani et al. 2006).

On receipt of the initial alert by $\text{HETE-2}$, a mosaic of images was triggered at the 1.5 m telescope of Observatorio de Sierra Nevada (OSN) in order to map the entire error box. The first

16 We point out that there is still an ongoing debate about the redshift of GRB 050509b, which could lie at a redshift of $z \sim 1.8$ (Berger 2006), although no optical or radio counterpart was found to support this scenario.
detection of the afterglow was obtained 22 minutes after the γ-ray event. Complementary observations were requested with the 2.2 m telescope of Calar Alto Observatory (Centro Astronómico Hispano Alemán [CAHA]), the 4.2 m William Herschel telescope (WHT) at Roque de los Muchachos Observatory, and the 3.5 m Astrophysical Research Consortium (ARC) telescope at Apache Point Observatory. Equatorials of the optical near-infrared (NIR) afterglow yielded R.A. = 09h09m 52s.02, decl. = +45°39' 45.9'' (J2000; 0.5'' uncertainty at 1σ level).

Optical images have been photometrically calibrated against the Sloan Digital Sky Survey (Adelman-McCarthy et al. 2006) by applying the corresponding transformations (Jester et al. 2005) for our photometric system. For NIR images, we have used field stars from the Two Micron All Sky Survey catalog (Skrutskie et al. 2006). A Galactic extinction (Schlegel et al. 1998) correction of $E(B-V)=0.014$ is applied, and magnitudes have been converted to flux density units (Jy) for clarity (Fukugita et al. 1995; Cox 2000). The photometric data are displayed in Table 1.

The X-ray light curve and spectrum were obtained from the Swift/XRT data. The spectrum was fit with a power law plus a fixed Galactic hydrogen column density ($N_{H(Gal)}=1.7\times10^{20}$ cm$^{-2}$) and an intrinsic column density $N_{H(int)}$ at a varying redshift in the range $0.1\leq z\leq6.0$ (Dickey & Lockman 1990). A spectral index ($\Gamma=\alpha+2$) of $\beta=1.10^{+0.04}_{-0.06}$ ($\chi^2$/degrees of freedom [dof] = 36/29) was derived from the fit with an intrinsic column density that, depending on the selected redshift scenario, ranges from $N_{H(z=1.7)}=0.46^{+0.23}_{-0.21}\times10^{22}$ cm$^{-2}$ to $N_{H(z=4.6)}=2.9^{+1.2}_{-1.5}\times10^{22}$ cm$^{-2}$.

### 3. RESULTS

The detections in the $I$, $R$, and $K$ bands and the upper limits imposed for the $U$, $B$, and $V$ bands allows us to construct a spectral flux distribution (SFD) at an epochs of 2.5 hr after the burst (Fig. 1). The NIR K-band point is extrapolated from a near epoch using as reference a quasi-simultaneous $K$ passband detection and assuming constant ($R-K$). The data were fitted with a power-law spectrum, a superposed intrinsic extinction (Pei 1992), and a Lyα blanketing model (Madau 1995) at a varying redshift. The slope of the power law was chosen to be $\beta_{opt}=0.60\pm0.09$, as derived from the X-ray spectra, assuming $\nu_{opt}<\nu<\nu_X$ at a prebreak epoch in the standard fireball model (Sari et al. 1999). This is confirmed by the modeling described below. We obtained two probability peaks in our redshift study. The main one (with a 63% likelihood) places the burst at $z=4.6\pm0.5$ with an intrinsic extinction of $A_V=0.5\pm0.2$ mag. A secondary peak (with a 35% likelihood) would imply that the afterglow lies at $z=1.7\pm0.4$ and $A_V=1.1\pm0.2$ mag. In either case, GRB 060121 is the farthest short-duration GRB detected to date. A redshift of $z<0.5$ has a likelihood $\lesssim0.5\%$ and implies extensions $A_{V}>1.8$. Adopting a flat cosmology with $\Omega_m=0.73$, $\Omega_{\Lambda}=0.27$, and $H_0=71$ km s$^{-1}$ Mpc$^{-1}$ and considering a γ-ray fluence of $(4.77\pm0.28)\times10^{-6}$ ergs cm$^{-2}$, we obtain an isotropic-equivalent energy release in γ-rays of $E_{\gamma,int}=2.4^{+0.1}_{-0.0}\times10^{52}$ ergs ($E_{\gamma,int}=3.7^{+0.6}_{-1.2}\times10^{52}$ ergs) for a redshift of $z=4.6$ (1.7), 2 (1) orders of magnitude higher than other $E_{\gamma,int}$ values determined for previous SPBs (Table 2). This is comparable to the values measured for LPBs (Frai et al. 2001).

We have modeled the GRB 060121 afterglow following the prescription of Jöhnsson et al. (2006) on the basis of the standard fireball model with two energy injections 0.035 and 0.23 days after the onset of the burst. These energy injections are required in order to explain the bumpy behavior seen during the first hours (Fig. 2); similar features have been seen in LPB light curves (Castro-Tirado et al. 2006) at $z<4$. The model has been fit for both $z=4.6$ and $z=1.7$ scenarios with slightly better results for the high-$z$ case ($\chi^2$/dof$_{z=4.6}=1.9$ vs. $\chi^2$/dof$_{z=1.7}=2.8$). We localize the cooling frequency between optical and X-ray, just below the X-ray measurements and the maximum frequency below the NIR. Together with the multiwavelength spectral slopes, the model parameters are constrained and, independent of the redshift, point to a narrow jet with a half-opening angle $\theta<10^\circ$ in a low-density environment ($10^{-3}\text{ cm}^{-3}\leq n \leq 0.1\text{ cm}^{-3}$); the lower density limit fits the observations better for the case in which the GRB took place at $z=4.6$, while the upper density value accommodates better the data at $z=1.7$, with efficiencies of conversion of kinetic energy.

### Table 1

OBSERVATIONS OF THE AFTERCASCADE OF GRB 060121

| Mean Date (2006 Jan) | Band | Telescope | Intrinsic Time (s) | Flux (μJy) |
|----------------------|------|-----------|-------------------|------------|
| 22:2443 …… | K | 4.2 m WHT | 750 | 17.1 ± 1.4 |
| 23:2402 …… | K | 4.2 m WHT | 1000 | 6.3 ± 1.6 |
| 23:3038 …… | K | 3.5 m ARC | 3600 | 7.48 ± 0.65 |
| 27:2588 …… | K | 3.5 m ARC | 3600 | <2.13 |
| 21:9405 …… | I | 1.5 m OSN | 120 | 19.3 ± 4.4 |
| 21:9633 …… | I | 1.5 m OSN | 120 | 10.0 ± 2.8 |
| 22:0458 …… | I | 1.5 m OSN | 300 | 10.8 ± 2.5 |
| 22:1162 …… | I | 1.5 m OSN | 6 × 300 | 4.55 ± 0.83 |
| 22:2539 …… | I | 1.5 m OSN | 5 × 300 | <2.5 |
| 22:0493 …… | R | 2.2 m CAHA | 600 | 3.70 ± 0.97 |
| 22:0963 …… | R | 2.2 m CAHA | 2 × 600 | 1.14 ± 0.33 |
| 22:1590 …… | R | 2.2 m CAHA | 2 × 600 | 1.23 ± 0.49 |
| 22:2385 …… | R | 2.2 m CAHA | 3 × 600 | 1.35 ± 0.37 |
| 23:1828 …… | R | 1.5 m OSN | 12 × 900 | <0.8 |
| 24:0804 …… | R | 2.2 m CAHA | 6 × 900 | 0.55 ± 0.14 |
| 22:0885 …… | V | 2.2 m CAHA | 2 × 600 | <1.1 |
| 22:1952 …… | V | 2.2 m CAHA | 5 × 600 | <0.7 |
| 22:0336 …… | B | 2.2 m CAHA | 600 | <1.7 |
| 22:1560 …… | B | 2.2 m CAHA | 7 × 600 | <0.9 |
| 22:0258 …… | U | 2.2 m CAHA | 600 | <3.3 |
| 22:1200 …… | U | 2.2 m CAHA | 5 × 600 | <2.1 |
to gamma-ray energy $\eta < 0.05$ (found when we maximize the opening angle in the fit while minimizing the initial energy). Although the jet break time cannot be accurately calculated from the available data, we find a steepening around 4 days after the burst in the best fit of the model.

4. DISCUSSION

GRB 060121 has a $T_{90}$ duration of 1.97 ± 0.06 s in the 85–400 keV energy band and a hardness ratio (HR) $H_{9}(100–300$ keV)/$H_{9}(50–100$ keV) = 1.48 ± 0.18. We note that the intrinsic duration of GRB 060121 would be 1.1 s with an HR of 3.0 if $z = 1.7$, or 0.7 s with an HR of 3.9 if $z = 4.6$, where in transforming $T_{90}$ to the rest frame we have taken into account both cosmological time dilation and the fact that the burst duration decreases with increasing energy. Both sets of values place GRB 060121 near the center of the cluster of BATSE SPBs in the ($T_{90}$, HR)-plane (see Fig. 3). We have studied the classification of GRB 060121 (as either an SPB or an LPB) using nine criteria: (1) duration, (2) pulse widths, (3) spectral hardness, (4) spectral lag, (5) energy radiated in $\gamma$-rays, (6) existence of a long, soft bump following the burst, (7) location of the burst in the host galaxy, (8) lack of detection of a supernova component to deep limits, and (9) type of host galaxy.

Four criteria (1, 5, 6, and 7) provide strong evidence that GRB 060121 is an SPB if $z = 1.7$, and two other criteria (2 and 4) provide additional strong evidence that GRB 060121 is an SPB if $z = 4.6$. None of the criteria provide evidence that GRB 060121 is an LPB. Thus, we can make a strong, although not conclusive, claim that GRB 060121 is an SPB. Further details about this analysis are given in Donaghy et al. (2006).

If we consider the progenitor to be a merger of compact objects (Eichler et al. 1989; Aloy et al. 2005), the released energy needs either a large conversion efficiency of the accreted mass into neutrino emission ($\gtrsim 0.05$), a large accretion disk mass ($\gtrsim 0.1 M_\odot$), or an appropriate combination of both factors.

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**TABLE 2**

| GRB  | Redshift | $T_{90}$ (s) | Fluence (ergs cm$^{-2}$) | $E_{\gamma,\text{iso}}$ (ergs) | $L_X$ (ergs s$^{-1}$) | $F_{50\text{keV}}$ |
|------|----------|--------------|--------------------------|----------------------------|---------------------|-----------------|
| 050509B | 0.225 | 0.04 | $9.5 \times 10^{-6}$ | $4.5 \times 10^{46}$ | $<7 \times 10^{41}$ | <0.005 |
| 050709 | 0.160 | 0.07 | $2.9 \times 10^{-6}$ | $6.9 \times 10^{46}$ | $3 \times 10^{41}$ | ~1.0 |
| 050724 | 0.258 | 3.00 | $6.3 \times 10^{-7}$ | $4.0 \times 10^{47}$ | $8 \times 10^{41}$ | ~0.2 |
| 050813 | 0.722 | 0.60 | $1.2 \times 10^{-6}$ | $6.5 \times 10^{47}$ | $9 \times 10^{41}$ | <0.15 |
| 051221A | 0.546 | 1.40 | $3.2 \times 10^{-6}$ | $2.4 \times 10^{47}$ | $6 \times 10^{41}$ | ~1.0 |
| 060121 | 1.7 | 1.97 | $4.8 \times 10^{-6}$ | $3.7 \times 10^{47}$ | $1.1 \times 10^{41}$ | ~20.0 |
| 060313 | ≤1.7 | 0.70 | $1.4 \times 10^{-6}$ | $2.4 \times 10^{47}$ | $6 \times 10^{41}$ | ~3.0 |

Note.—The table displays, in columns from left to right, the name of the burst, redshift, duration of the gamma-ray emission, measured $\gamma$-ray fluence, isotropic-equivalent $\gamma$-ray energy, isotropic-equivalent luminosity observed in X-rays 10 hr after the burst, and the fraction of afterglow flux 12 hr after the burst and the host galaxy flux (both in the $R$ band). The compilation is based on this work, Fox et al. (2005), Schady & Pagani (2006), Golenetskii et al. (2006b), Soderberg et al. (2006), and references therein.

See footnote 16 in text.

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**Fig. 2.**—Light curve of the afterglow in the near-infrared ($K_{s}$), visible ($R$ and $I$), and X-ray bands. The figure shows the result of the best fit of the model in the most probable high-$z$ (4.6) case, which has been optimized with values of $\rho = 2.06$, $\theta_0 = 0.6$, and $n = 0.1$ cm$^{-3}$, and in the low-$z$ (1.7) case, which gives a slightly worse fit with $\rho = 2.05$, $\theta_0 = 2.3$, and $n = 0.04$ cm$^{-3}$. The filled symbols are data from the literature. [See the electronic edition of the Journal for a color version of this figure.]

**Fig. 3.**—Burst duration vs. spectral hardness diagram. The large black circles are the locations of the three currently established HETE-2 short GRBs superposed on the distribution of 1973 BATSE short and long GRBs (small gray dots).

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(Oechslin & Janka 2006). Considering a merger at a redshift \( z > 1.5 \), there is a higher consistency with the theoretical models for which the rate of NS+NS or NS+BH mergers follows the star formation rate with delays of \( \sim 1 \) Gyr (Janka et al. 2006) than with those of very old populations of NS+NS progenitor systems (Nakar et al. 2005). Furthermore, the high extinction derived from the SFD fit indicates that the merger probably took place within the galaxy rather than in the outer halo or intergalactic medium, and thus the system received a small natal kick, although the density of the local event environment is relatively low (\( n \sim 0.1 \) cm\(^{-3} \)), as indicated by the afterglow fits discussed here. Alternatively, if the energy was extracted via a Blandford-Znajek process (Blandford & Znajek 1977), either the value of the dimensionless angular momentum of the central BH is \( a > 0.3 \), the magnetic field surrounding the BH is \( B \geq 10^{16} \) G, or the BH has a mass larger than \( 3 M_\odot \) (or a combination of these parameters).

Late observations by the *Hubble Space Telescope* (*HST*) have shown no trace of the afterglow down to the magnitude \( R \sim 28 \) about 37 days after the burst but do show an underlying galaxy (Levan et al. 2006). We have reanalyzed the photometry of the galaxy using ColorPro (Coe et al. 2006), obtaining \( F606W_{\lambda 0} = 27.35 \pm 0.16 \) (\( HST \) wideband filter centered at 606 nm) and \( F160W_{\lambda 0} = 24.05 \pm 0.38 \) (\( HST \) wideband filter centered at 1600 nm). Although the information is very limited, we have used this photometry to study the probability distribution for the redshift of the galaxy using a Bayesian photometric redshift as described by Benítez (2000) and Benítez et al. (2004). We obtain two peaks of probability at \( z = 1.0 \) and \( z = 5.2 \), the latter being more probable. By multiplying this probability by the one obtained for the afterglow, we can assign a probability of 70% to the higher redshift case and a probability of 28% to the lower redshift scenario (see Fig. 4). Applying a prior based on well-determined extinctions for LPBs (Kann et al. 2006), the likelihood of a high-redshift event would rise to 98% as no bursts are usually found with high extinction. This is a soft constraint as it favors low extinctions, like it could be expected from the low density derived from our model, which is significantly lower than the one found for LPBs.

5. CONCLUSION

These results suggest that assuming that GRB 060121 were an SPB, there exists an emerging population of short events located at high redshifts and with isotropic energy releases of \( E_{\gamma,\,iso} \sim 10^{53} - 10^{55} \) ergs similar to the values observed in long events. Furthermore, following the classification by Horváth et al. (2006), GRB 060121 could be classified in the intermediate group (Horváth 1998; Balasgati et al. 2001) of events with a 68% probability (28% for short burst and 4% for long burst). The relationship between this second population of short bursts and the intermediate population of GRBs will be determined or excluded by future observations.

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REFERENCES

Adelman-McCarthy, J. K., et al. 2006, ApJS, 162, 38
Aloy, M. A., Janka, H.-T., & Müller, E. 2005, A&A, 436, 273
Arimoto, M., et al. 2006, GCN Circ. 4550
Balasgati, A., Ruiz-Lapuente, P., & Canal, R. 2001, MNRAS, 328, 283
Barthelmy, S. D., et al. 2005, Nature, 438, 994
Benítez, N. 2000, Apl, 536, 751
Benítez, N., et al. 2004, ApJS, 150, 1
Berger, E. 2006, preprint (astro-ph/0602004)
Berger, E., et al. 2005a, Nature, 438, 988
———. 2005b, ApJ, 634, 501
Blandford, R. D., & Znajek, R. L. 1977, MNRAS, 179, 333
Boer, M., et al. 2006, GCN Circ. 4552
Castro-Tirado, A. J., et al. 2006, A&A, submitted
Coe, D., Benítez, N., Sánchez, S. F., Jee, M., Bouwens, R., & Ford, H. 2006, 
AJ, 132, 926
Covino, S., et al. 2006, A&A, 447, L5

Cox, A. N. 2000, Allen's Astrophysical Quantities (4th ed.; New York: AIP)
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Donaghy, T. Q., et al. 2006, ApJ, submitted (astro-ph/0605570)
Eichler, D., Livio, M., Piran, T., & Schramm, D. N. 1989, Nature, 340, 126
Fox, D. B., et al. 2005, Nature, 437, 845
Frail, D. A., et al. 2001, ApJ, 562, L5
Fukugita, M., Shimasaku, K., & Ichikawa, T. 1995, PASP, 107, 945
Gehrels, N., et al. 2005, Nature, 437, 851
Golenetskii, S., et al. 2006a, GCN Circ. 4564
———. 2006b, GCN Circ. 4881
Hjorth, J., et al. 2005, Nature, 437, 859
Horváth, I. 1998, ApJ, 508, 757
Horváth, I., Balázs, L. G., Bagoly, Z., Ryde, F., & Mészáros, A. 2006, A&A, 447, 23
Jakobsson, P., et al. 2006, A&A, 447, 897
Janka, H.-Th., Aloy, M.-A., Mazzali, P. A., & Pian, E. 2006, ApJ, 645, 1305

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Jensen, B. L., et al. 2001, A&A, 370, 909
Jester, S., et al. 2005, AJ, 130, 873
Jóhannesson, G., Björnsson, G., & Gudmundsson, E. H. 2006, ApJ, 647, 1238
Kann, D. A., Klose, S., & Zeh, A. 2006, ApJ, 641, 993
Kouveliotou, C., et al. 1993, ApJ, 413, L101
Levan, A. J., et al. 2006, ApJL, submitted (astro-ph/0603282)
Madau, P. 1995, ApJ, 441, 18
Malesani, D., et al. 2006, GCN Circ. 4561
Mangano, V., et al. 2006, GCN Circ. 4560
Nakar, E., Gal-Yam, A., & Fox, D. B. 2005, preprint (astro-ph/0511254)

Oechslin, R., & Janka, H.-T. 2006, MNRAS, 368, 1489
Pei, Y. C. 1992, ApJ, 395, 130
Sakamoto, T., et al. 2006, in AIP Conf. Proc. 838, Gamma-Ray Bursts in the Swift Era, ed. S. S. Holt, N. Gehrels, & J. A. Nousek (Melville: AIP), 43
Sari, R., Piran, T., & Halpern, J. P. 1999, ApJ, 519, L17
Schady, P., & Pagani, C. 2006, GCN Circ. 4877
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Skrutskie, M. F., et al. 2006, AJ, 131, 1163
Soderberg, A. M., et al. 2006, preprint (astro-ph/0601455)
van Paradijs, J., Kouveliotou, C., & Wijers, R. A. M. J. 2000, ARA&A, 38, 379
Villasenor, J. S., et al. 2005, Nature, 437, 855