GRB 070429B AND 070714B: THE HIGH END OF THE SHORT-DURATION GAMMA-RAY BURST REDSHIFT DISTRIBUTION

S. BRADLEY CENKO\^2, EDO BERGER\^3,4,5, EHUD NAKAR\^6, MANSI M. KASLIWAL\^7, ANTONIO CUCCHIARA\^8, SHRI K. KULKARNI\^7, ERAN OFEK\^7, DEREK B. FOX\^9, FIONA A. HARRISON\^10, ARNE RAU\^1, PAUL A. PRICE\^9, AVISHAY GAL-YAM\^10, MICHAEL A. DOPITA\^11, BRYAN E. PENPRASE\^12

ABSTRACT

We present optical spectra of the host galaxies of the short-duration gamma-ray burst GRB 070429B and the likely short-duration with extended emission GRB 070714B. In both cases, we find a single emission line that we identify as [O II] $\lambda$ 3727 at $z \sim 0.9$. Both events are more distant than any previous short-duration GRB with a secure host association from the sub-arcsecond position of an optical afterglow. GRBs 070429B and 070714B provide strong evidence in support of our previous claims in Berger et al. that a significant fraction of short-duration hosts ($\geq 33\%$) reside at $z > 0.7$. We discuss the implications of the existence of short-duration GRBs, as well as on progenitor models. In the context of the degenerate binary merger scenario, such events require progenitor systems with a range of lifetimes and disfavor progenitor models with a long, narrow lifetime distribution.

Subject headings: gamma-rays: bursts

1. INTRODUCTION

Much like their long-duration cousins, the discovery of the first X-ray (Gehrels et al. 2005; Bloom et al. 2006), optical (Hjorth et al. 2005), and radio (Berger et al. 2005b) afterglows of short-duration ($\Delta t \lesssim 2$ s) gamma-ray bursts (GRBs) has driven great progress in recent years. Based primarily on the discovery of the first four afterglows, GRB 050509B ($z = 0.225$; Gehrels et al. 2005; Bloom et al. 2006), GRB 050709 ($z = 0.1606$; Villasenor et al. 2005), Hjorth et al. 2005; Fox et al. 2005; Berger et al. 2005b; Barthelmy et al. 2005a; Grupe et al. 2006), and GRB 051221 ($z = 0.5465$; Soderberg et al. 2006; Burrows et al. 2006), a general picture of short-duration GRB hosts quickly emerged. Unlike long-duration events, short-duration GRBs occur in both early- and late-type galaxies, all at relatively low redshift (compared to $z \approx 3$ for long-duration Swift GRBs: Berger et al. 2005b; Jakobsen et al. 2006). If, as is widely believed, short-duration GRBs result from coalescence of a compact binary (neutron star – neutron star [NS-NS] or neutron star – black hole [NS-BH]; Eichler et al. 1989), these nearby events imply a long progenitor delay time ($\tau > 4$ Gyr; Nakar et al. 2006), inconsistent with the properties of such systems observed in the Milky Way.

In a recent work, Berger et al. (2007) have searched the afterglow error circles of nine additional short-duration bursts without an established redshift, identifying a population of faint ($R \sim 23 - 26$ mag) putative host galaxies. Spectroscopy of the brightest four of these galaxies indicate they lie at $0.4 < z < 1.1$, while a comparison with field galaxies indicates the fainter hosts likely reside at $z \geq 1$. The implications of the existence of a high-redshift ($z > 0.7$) population of short-duration bursts would be profound, in terms of the implied isotropic energy release ($E_{iso} \sim 10^{50} - 10^{51}$ erg), the progenitor delay times (both shorter and a broader distribution), and the possibility of detection with ground-based gravitational wave detectors.

In this Letter, we present spectra of the host galaxies of two recent GRBs: the short-duration GRB 070429B and the likely short-duration with extended emission GRB 070714B. Both events have detected optical afterglows, providing both a secure host association and a secure redshift, thereby overcoming the primary limitation of our previous statistical study. Both hosts lie at $z \sim 0.9$, providing strong evidence in favor of a substantial population of high-redshift short-duration bursts. We conclude by discussing the impact of this population on short-duration burst progenitor models.

2. GRB 070429B

The Burst Alert Telescope (BAT; Barthelmy et al. 2005a) on board Swift detected and localized GRB 070429B at 03:09:04 UT (Markwardt et al. 2007). The duration of the prompt emission was measured to be $t_{90} = 0.5 \pm 0.1$ s, placing the event firmly in the short-duration category (Tueller et al. 2007). Fitting a power-law with index $\Gamma = 1.71 \pm 0.23$, Tueller et al. (2007) measure a prompt fluence of $F_{\gamma} = (6.3 \pm 1.0) \times 10^{-8}$ erg cm$^{-2}$ in the 15 – 150 keV band.

The fading X-ray afterglow was identified by the X-
We obtained a spectrum of this object with the Low Resolution Imaging Spectrograph (LRIS; Oke et al. 1995) mounted on the 10-m Keck I telescope on the night of 12 August 2007. Two 1800 s exposures were taken at high air mass (∼1.9) with the 0″7 slit. We employed a dichroic at 5600 Å to split the beam in two. The 400/8500 grating on the red side provides coverage from 5600 − 8500 Å, with a dispersion of 1.86 Å pixel⁻¹. The 400/3400 grism was responsible for the dispersion on the blue end, resulting in coverage from the atmospheric cut-off up to ∼ 5600 Å and a dispersion of 1.09 Å pixel⁻¹.

Spectra were reduced in the IRAF13 environment using standard routines. Dithered spectra were subtracted to remove residual sky lines. Cosmic rays were removed using the LA Cosmic routine (van Dokkum 2001). The resulting spectrum was extracted optimally (Horne 1986) and wavelength calibration was performed first relative to calibration lamps and then tweaked based on night sky lines. Both air-to-vacuum and heliocentric corrections were then applied to all spectra. Extracted spectra were divided through by a smoothed flux standard to remove narrow band (< 50 Å) instrumental effects (Bessel 1999). Flux calibration was performed relative to the spectrophotometric standard Feige 11 (Stone 1996). To account for slit losses, we scaled the resulting spectrum to match the measured photometric g' - and R-band magnitudes (Perley et al. 2007a). Finally, we de-reddened the spectrum to account for the modest Galactic extinction: E(B-V) = 0.027 (Schlegel et al. 1998).

The resulting spectrum of the host galaxy of GRB 070429B is shown in Figure 2. We find a single faint emission line at λ = 7091.2 ± 0.6 Å. Due to the lack of blueward features, we identify this line as [O II] λ 3727 at a redshift of z = 0.9023 ± 0.0002. Fitting the line with a Gaussian profile, we measure a flux of F = (3.8 ± 1.2) × 10⁻¹⁷ erg cm⁻² s⁻¹. Adopting the most recent ΛCDM parameters for a flat universe from WMAP (H₀ = 73 km s⁻¹ Mpc⁻¹; Ω_m = 0.24, Ω_Λ = 1 − Ω_m; Spergel et al. 2007), and using the transformation from Kennicutt (1998), we infer a star formation rate of 1.1 ± 0.5 M⊙ yr⁻¹. Correcting for the rest-frame B-band luminosity, we find a specific star formation rate of φ ≈ 2.5 ± 1.1 M⊙ yr⁻¹ L⊙⁻¹. We caution, however, these values are only lower limits, as they do not incorporate any extinction native to the host. These results are in overall agreement with the findings in the GCN13 circular of Perley et al. (2007a).

3. GRB 070714B

GRB 070714B was detected by the Swift-BAT at 04:59:29 UT on 17 July 2007 (Racusin et al. 2007b). Using the best-fit power-law spectrum with index Γ = 1.36 ± 0.19, the 15 − 150 keV fluence in the prompt emission was measured to be Fₚ = (5.1 ± 0.3) × 10⁻⁷ erg cm⁻². While the duration of the prompt emission is significantly longer than the canonical long-short divide (t₉₀ = 64 ± 5 s), the burst light curve is comprised of several short spikes (duration ∼ 3 s) with a long, soft tail (Barbier et al. 2007). The spectral lag is consistent with zero (Norris et al. 2007), a property typically observed in short-duration bursts (Norris & Bonnell 2006). Like GRBs 050709 and 050724, GRB 070714B therefore appears likely associated with a long-lifetime jet.


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GRBs 070429B and 070714B

4. DISCUSSION

In summary, we present the redshifts of the host galaxies of the short-duration GRB 070429B (z = 0.902) and the short-duration with extended emission GRB 070714B (z = 0.922). These are the two highest redshifts for short-duration GRBs with detected optical afterglows, making the GRB-host associations robust. Our results lend credence to the primary conclusions of our previous study of short-duration GRB hosts and their redshifts, which was based in part on XRT positions (≤ 5′′), and in some cases on probabilistic redshifts from host magnitudes.

We now attempt to estimate the contribution of high-redshift galaxies to the observed short-duration population. We first consider only those short-duration events with optical afterglows (and hence secure host identifications) and secure host redshifts (from spectroscopy): GRBs 050709 (z = 0.16), 050724 (z = 0.26), 051221A (z = 0.55), 061006 (z = 0.44; Berger et al. 2007), and the two hosts presented here. High redshift (z > 0.7) hosts constitute 33% of this sample. However, because these events are biased towards the brightest (and therefore, probabilistically, most nearby) hosts (see Berger et al. 2007, Fig. 8), we also consider three additional events with secure hosts but no host redshifts (due primarily to faintness): GRBs 060313 (Roming et al. 2006), 060121 (Levan et al. 2006; de Ugarte Postigo et al. 2006), and 051227 (Berger et al. 2007). If, as is likely from their faintness, all three events lie at z > 0.7, the percentage of high redshift short-duration GRBs may be as high as 56%. We note that this result does not change dramatically if we include XRT-host associations (e.g. GRBs 050509B and 060502B). The range of one- to two-thirds is in line with our previous analysis. However, we caution that the errors on these estimates are quite large due to small number statistics, and we do not consider here any selection effects associated with the above samples.

At z ~ 0.9, the isotropic prompt energy release from GRB 070429B is $E_{\gamma,\text{iso}} = 1.4 \pm 0.2 \times 10^{50}$ erg, while the corresponding value for GRB 070714B is $E_{\gamma,\text{iso}} = 1.2 \pm 0.1 \times 10^{51}$ erg. These values are several orders of magnitude larger than most of the previously established short-duration GRBs at z < 0.5, though still well short of typical values for long-duration events ($E_{\gamma,\text{iso}} \gtrsim 10^{52}$ erg; Butler et al. 2007). The X-ray luminosity at $t = 1$ d, $L_{X,1}$, extrapolated from the online Swift X-ray light curve repository (Evans et al. 2007), is consistent with the correlation found between $L_{X,1}$ and $E_{\gamma,\text{iso}}$ found for the majority of short-duration events (Nakar 2007; Berger 2007). Like long-duration events, collimation corrections may play an important role in the total energy budget for short-duration bursts (e.g. GRB 051221A; Soderberg et al. 2006; Burrows et al. 2006). However, if a full 56% of short-duration events reside at z > 0.7, the energy release of short-duration events may approach the canonical long-duration value of $E_{\gamma} \sim 10^{51}$ erg (Frail et al. 2001; Berger et al. 2003).
Energies in excess of $10^{51}$ erg are difficult to explain in the context of $\nu \bar{\nu}$ annihilation models (Rosswog & Ramirez-Ruiz 2002), and may instead favor energy extraction via magnetohydrodynamic processes (e.g. Blandford & Znajek 1977).

Much as with energetics, the specific star formation rate of GRB 070429B falls intermediate between the nearby short-duration events ($\phi \lesssim 1 \text{ M}_\odot \text{ yr}^{-1} \text{ L}^{-1}$; Nakar et al. 2007 and references therein) and long-duration GRBs ($\phi \sim 10 \text{ M}_\odot \text{ yr}^{-1} \text{ L}^{-1}$; Christensen et al. 2004). The specific star formation rate of GRB 070714B, however, is more consistent with the long-duration population, although large errors preclude any firm conclusions from being drawn.

The detection of short-duration GRBs in late-type galaxies at $z \gtrsim 1$ is more consistent with our current understanding of compact binary coalescence models (e.g. Guetta & Piran 2006; Hopkins et al. 2006; Nakar et al. 2006). Progenitor models with long delay times ($\tau \sim 6$ Gyr) and narrow, lognormal distributions ($\sigma \sim 0.3$) were consistent with previous analyses based solely on the most nearby events. Our results here favor models with a shorter characteristic delay time ($\tau \sim 4$ Gyr), but much broader distribution ($\sigma \sim 1$; Nakar et al. 2006). Further studies with a significantly expanded sample will be required for a detailed comparison of the properties of short-duration hosts with those predicted by compact binary merger models (e.g. Belczynski et al. 2006).

Based on inferences at this phase, a possible progenitor for GRB 070714B is a binary system with a relatively tight orbit, one of which is at least a neutron star.}

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