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GRB 050826: A SUBLUMINOUS EVENT AT $z = 0.296$ FINDS ITS PLACE IN THE LUMINOSITY DISTRIBUTION OF GAMMA-RAY BURST AFTERGLOWS

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ABSTRACT

We present the optical identification and spectroscopy of the host galaxy of GRB 050826 at redshift $z = 0.296 \pm 0.001$. Image subtraction among observations obtained on three consecutive nights reveals a fading object 5 hr after the burst, confirming its identification as the optical afterglow of this event. Deep imaging shows that the optical afterglow is offset by 0.4″ (1.76 kpc) from the center of its irregular host galaxy, which is typical for long-duration gamma-ray bursts. Combining these results with X-ray measurements acquired by the *Swift* XRT instrument, we find that GRB 050826 falls entirely within the subluminous, subenergetic group of long gamma-ray bursts at low redshift ($z \lesssim 0.3$). The results are discussed in the context of models that possibly account for this trend, including the nature of the central engine, the evolution of progenitor properties as a function of redshift, and incompleteness in current gamma-ray burst samples.

Subject headings: gamma rays: bursts — supernovae: general

1. INTRODUCTION

Understanding the progenitor responsible for gamma-ray bursts (GRBs) is a fundamental problem in stellar evolution models. Whereas it is now generally accepted that a fraction of GRBs is associated with the deaths of massive stars (Galama et al. 1998; Hjorth et al. 2003; Stanek et al. 2003), considerable uncertainty remains as to what the precise nature of the progenitor system is, including its evolutionary stage. The range of potential progenitors seems to be restricted to rapidly rotating, highly stripped massive stars, either in isolation (Woosley & Heger 2006) or spun up in close binary systems (Fryer et al. 1999). Unfortunately, neither of these possibilities can yet be definitely excluded (Gal-Yam et al. 2005).

One key to addressing the origin of GRBs lies with the growing sample of low-redshift ($z \lesssim 0.3$) events (e.g., Mirabal et al. 2006). According to recent observations, subenergetic, subluminous GRBs/supernovae dominate the local population of GRB events (Cobb et al. 2006; Liang et al. 2006; Pian et al. 2006; Soderberg et al. 2006). However, with a handful of low-redshift events, it remains unclear whether this trend is due to unusual progenitor properties (MacFadyen & Woosley 1999) or an intrinsic difference in the central engine, i.e., black hole versus magnetar (Mazzali et al. 2006; Soderberg et al. 2006). We therefore have set out to find the tell-tale signatures of low-redshift bursts in *Swift* afterglows, i.e., a bright host galaxy in pre- or postburst observations, the identification of emission lines associated with a low-redshift starburst galaxy, and/or the rise in supernova light. Our ultimate goal is to uncover the redshift distribution, host galaxy properties, and metal content of the nearest progenitor systems.

In this Letter we report optical and X-ray observations of the nearby GRB 050826, which we localize to an irregular galaxy at $z = 0.296$. We begin with a description of the observations and the discovery of the optical transient (OT) using image subtraction. We then discuss the properties of its host galaxy and X-ray afterglow emission that support a subluminous classification for this event, when compared to cosmic GRBs. Finally, we consider the role of image subtraction in completing the census of low-luminosity GRBs in nearby galaxies and give an outlook on future work. Throughout this Letter we assume $H_0 = 71$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.27$, and $\Omega_\Lambda = 0.73$, corresponding to a luminosity distance $D_L = 1517$ Mpc.

2. OBSERVATIONS

2.1. *γ-Rays and X-Rays*

GRB 050826 was detected with the *Swift* Burst Alert Telescope (BAT) on UT 2005 August 26.2626 (Mangano et al. 2005b). The BAT light curve consists of a multiple-peak structure with $t_{90} = 35 \pm 8$ s (Markwardt et al. 2005), measuring $(4.3 \pm 0.7) \times 10^{-7}$ ergs cm^{-2} in the 15–150 keV band. While the main burst is weak and hard in the BAT energy range, the duration is consistent with a classical long burst (Kouveliotou et al. 1993).

The *Swift* X-ray Telescope (XRT) collected data on GRB 050826 from 106 s up to 2.45 days after the BAT trigger. The processed XRT data presented here have been assembled from a previous analysis of the X-ray emission for a sample of *Swift* GRBs (O'Brien et al. 2006). Standard processing of the data was performed using XRTPIPELINE version 0.8.8 that were then converted into unabsorbed X-ray fluxes.

Figure 1 shows the resulting XRT light curve in the 0.3–10 keV bandpass. The temporal decay of the X-ray afterglow is well fitted by a single power-law model $f \propto t^{\alpha_X}$ with a decay index $\alpha_X = -1.10 \pm 0.08$ (see also Willingale et al. 2007). From the full spectrum, we obtain a power-law fit with spectral index $\beta_X = -1.27 \pm 0.47$ and $N_H = 6.5 \times 10^{21}$ cm^{-2}, in excess of the Galactic value $N_H = 2.2 \times 10^{21}$ cm^{-2}.

2.2. *Optical*

The *Swift* UV/Optical Telescope (UVOT) began observing the field of GRB 050826 just 105 s after the BAT trigger. No new sources were found within the XRT error circle to 3 σ limiting magnitudes of $B > 21.2$ and $V > 19.4$ (Blustin et al. 2005). Follow-up optical observations with the MDM 1.3 m telescope commenced on 2005 August 26.450 UT and continued for three consecutive nights until 2005 August 28.480 UT (Halpern 2005). Additional late-time observations of the region were obtained on 2005 December 25.310 (Halpern & Mirabal

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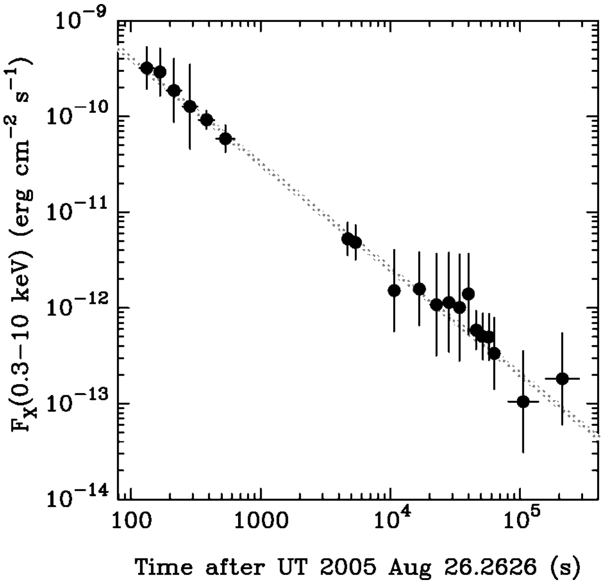

FIG. 1.—XRT light curve (0.3–10 keV) of GRB 050826. The data are well described by a power-law decay index $\alpha_X = -1.10 \pm 0.08$.

2006a) and 2007 February 6.135 using the 2.4 m and 1.3 m MDM telescopes, respectively.

An object not visible on the Digital Sky Survey is detected at α(J2000.0) = $05^h51^m01.58^s$, δ(J2000.0) = $-02°38'35.8''$ on the August 26.472 image. This position was originally 8″away from the initial XRT localization (Mangano et al. 2005a). Subsequently, the XRT position (Fig. 2) was revised to include the optical candidate within the XRT error circle (Moretti et al. 2006; Butler 2007). To search for optical variability among our images, we performed image subtraction between the August 26.472 and 28.480 pointings. The resulting difference reveals a pointlike OT 5 hr after the burst and shows that the galaxy begins to dominate after the August 26.472 epoch. In Figure 2, we show the OT position derived from image subtraction overlaid over the presumed host galaxy. A summary of the optical photometry measured on the residual images is given in Table 1.

TABLE 1
OPTICAL PHOTOMETRY OF GRB 050826

Date (UT)	Filter	Magnitude[a]
August 26.472	*R*	20.66 ± 0.15
August 27.473	*R*	>21.24
August 28.480	*R*	>21.24

[a] The data have been corrected for Galactic extinction $A_R = 1.57$. No extinction intrinsic to the GRB host is included.

Spectra of the host galaxy were obtained on 2006 December 24 UT using the Boller & Chivens CCD Spectrograph (CCDS) mounted on the MDM 2.4 m telescope. A total of three 3600 s exposures were acquired in a 1.5″ slit by blind offset from a nearby field star. The spectra were processed using standard procedures in IRAF [3] and applying the wavelength calibration from Xe lamp spectra. Flux calibration was performed using the spectrophotometric standard Feige 34. Finally, the data were dereddened from significant Galactic extinction in this direction, $E(B-V) = 0.59$ (Schlegel et al. 1998). Figure 3 shows the summed wavelength-calibrated spectrum of the host galaxy.

3. RESULTS

Narrow emission lines corresponding to [O II] λ3727, and [O III] λλ4959, 5007 are seen in the summed spectrum (Fig. 3). The line strengths are similar to those of well-studied GRB hosts (Wiersema et al. 2007). The weighted mean heliocentric redshift is $z = 0.296 \pm 0.001$, thus confirming the initial redshift interpretation by Halpern & Mirabal (2006b). Unfortunately, abun-

[3] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

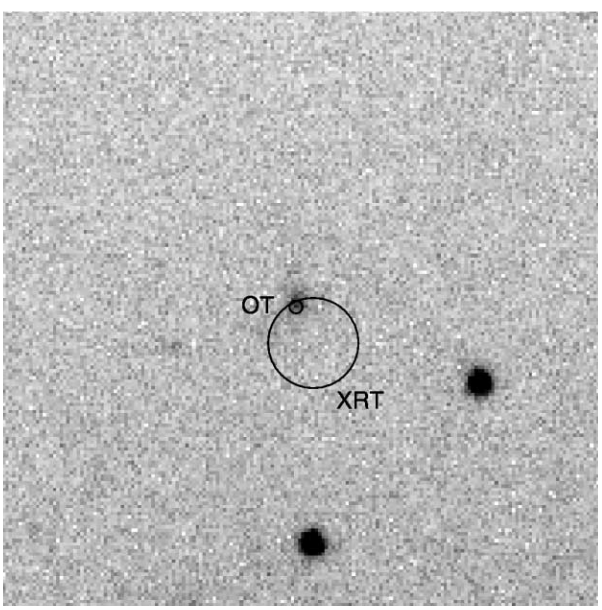

FIG. 2.—*R*-band image of the host galaxy of GRB 050826 observed with the MDM 2.4 m telescope on UT 2005 December 25.31. The magnitude of the host is measured to be $R_{host} = 19.67 \pm 0.05$. The localization of the OT using image subtraction is shown by the inner circle. Also shown is the final XRT error position with a 3.4″radius from Moretti et al. (2006). The field is 45″ across.

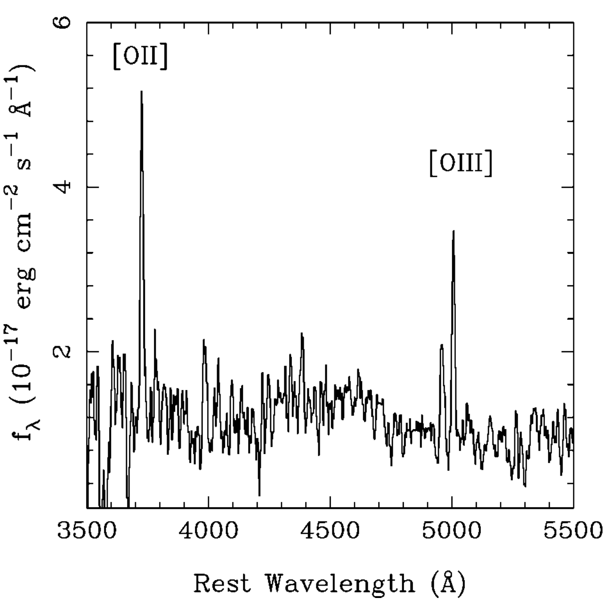

FIG. 3.—Optical spectrum of the host galaxy of GRB 050826 obtained at the MDM 2.4 m telescope on 2006 December 24 UT. Narrow emission lines corresponding to [O II], and [O III] are clearly detected. The spectrum is corrected for Galactic extinction following a Cardelli et al. (1989) law. No extinction intrinsic to the GRB host is included.

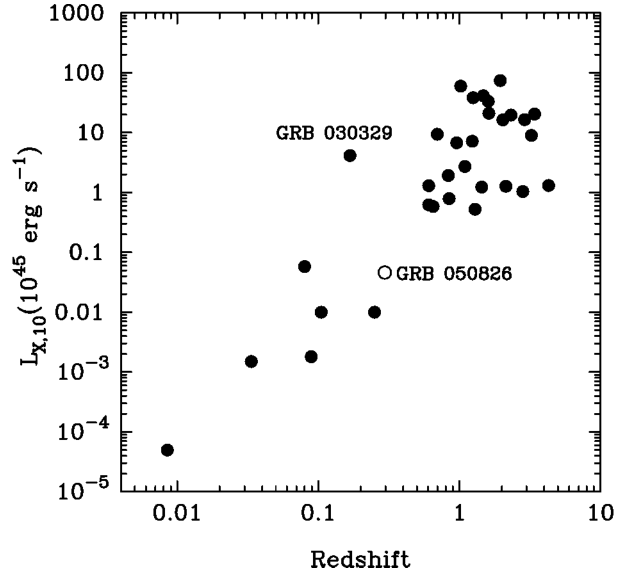

FIG. 4.—Isotropic X-ray luminosity $L_{\rm X,\,10}$ in the 2–10 keV band estimated at $t = 10$ hr (source frame) as a function of redshift (*filled circles*) culled from the samples by Berger et al. (2003) Nousek et al. (2006) and Amati et al. (2007). The open circle indicates the location of GRB 050826 in the distribution. This is a flux-limited sample.

dance measurements require the Hβ intensity, which was impeded by the bright [O I] night-sky line at ≈6300 Å.

At a redshift of $z = 0.296$, the BAT γ-ray fluence $(4.3 \pm 0.7) \times 10^{-7}$ ergs cm^{-2} in the 15–150 keV band (Markwardt et al. 2005) yields an isotropic energy of $E_{\rm iso} = (9.1 \pm 1.3) \times 10^{49}$ ergs. The simplest afterglow emission model consistent with the X-ray observations corresponds to the regime when $\nu_{\rm X} > \nu_c$, so that $\beta_{\rm X} = -p/2$ and $\alpha_{\rm X} = (2 - 3p)/4$ (Granot & Sari 2002). Here p is the electron spectral index, and ν_c is the synchrotron cooling frequency. This implies $p = 2.13 \pm 0.1$ with either a constant density or a stellar wind circumburst environment. We note that a burst seen off-axis should show a rising light curve (Granot et al. 2005), which is not detected in this case.

The lack of a break in the X-ray light curve prior to 2.45 days postburst constrains the half-opening angle of the expanding jet to $\theta_0 0.38 n_0^{1/8}$ (Sari et al. 1999), where n_0 is the circumburst density in cm^{-3}. Such a wide opening angle appears to strain the degree of collimation in the GRB outflow when compared to well-studied events (Zeh et al. 2006); however, it is difficult to ascertain the implications of our results for GRB jet models without additional late X-ray data. As a result the γ-ray release in the 15–150 keV band is bracketed by $E_\gamma = (0.6\text{–}9.1) \times 10^{49}$ ergs. Similarly, the available limits on the afterglow luminosity in the 2–10 keV band at $t = 10$ hr (source frame) correspond to $L_{\rm X,\,10} = (0.3\text{–}4.6) \times 10^{43}$ ergs s^{-1}.

Inspection of the host galaxy of GRB 050826 in the late-time observations reveals a bright core and an irregular morphology extended southeast (Fig. 2). Photometry of the host galaxy performed in a 3″ radius aperture centered on the host nucleus yields $R = 21.24 \pm 0.05$ and $V = 22.53 \pm 0.06$, respectively. Correcting for the amount of Galactic extinction, we adopt $R_{\rm host} = 19.67 \pm 0.05$ and $V_{\rm host} = 20.59 \pm 0.06$, as the unextincted magnitudes of the host galaxy. Within the current concordance cosmology, the implied rest-frame absolute magnitude corresponds to $M_B \approx -19.7$, which is well within the distribution of GRB host magnitudes at redshift $z < 1.2$ (Fruchter et al. 2006). We therefore conclude that the host luminosity is $L_{\rm host} \approx 0.3 L_*$, with $M_* = -21.0$ (Christensen et al. 2004).

From the observed flux in the [O II] λ3727 line $F_{3727} = (1.1 \pm 0.1) \times 10^{-15}$ ergs cm^{-2} s^{-1}, we derive the line luminosity $L_{3727} = (2.3 \pm 0.3) \times 10^{41}$ ergs s^{-1}. Following the conversion from Kennicutt (1998), the implied star formation rate corresponds to SFR ≈ (3.2 ± 1.5) $M_\odot$ yr^{-1}. Thus, the inferred SFR of the host galaxy lies in the range 0.7–12 $M_\odot$ yr^{-1} calculated for GRB hosts at higher redshifts (Christensen et al. 2004).

The small projected OT displacement from the host center 0.4″ (≈1.76 kpc, Fig. 2) implies that the GRB position correlates with the light of its host (Bloom et al. 2002). The chance superposition between the optical transient and a foreground galaxy of equal or greater brightness within the observed offset is $\approx 4 \times 10^{-5}$ (Huang et al. 2001), which strengthens its association with this nearby galaxy. As such, the host displays an irregular morphology analogous to those observed in other GRB hosts (Fruchter et al. 2006). Unfortunately, it is difficult to determine cleanly whether the southeast extension corresponds to neighboring galaxies or is related to a continuation of the host stellar field.

4. DISCUSSION

A recent inventory of the prompt and afterglow emission of the GRB population reveals that subluminous, subenergetic GRBs dominate the local population ($z \lesssim 0.3$) of GRB events (Cobb et al. 2006; Liang et al. 2006; Pian et al. 2006; Soderberg et al. 2006; Kaneko et al. 2007). In order to place GRB 050826 in the emerging taxonomy of GRBs, we plot its isotropic X-ray luminosity $L_{\rm X,\,10}$ in the 2–10 keV band estimated at $t = 10$ hr (source frame) as a function of redshift (Fig. 4). For comparison we also show the luminosity distribution of $L_{\rm X,\,10}$ measurements from the samples amassed by Berger et al. (2003), Nousek et al. (2006), and Amati et al. (2007).

From the collection, it is apparent that GRB 050826 falls below the least luminous GRB at $z \gtrsim 0.3$. Moreover, for all but one low-redshift ($z \lesssim 0.3$) burst, the isotropic afterglow luminosity is bounded by $L_{\rm X,\,10} \lesssim 10^{44}$ ergs s^{-1}. The single exception is GRB 030329, whose true luminosity reduces to $L_{\rm X,\,true} \lesssim 4 \times 10^{43}$ ergs s^{-1} after the beaming fraction is included (Gorosabel et al. 2006). We note that the true X-ray luminosity for higher redshift ($z \gtrsim 0.3$) events will be equally dependent on collimation corrections. However, collimation-corrected luminosities inferred for $z \gtrsim 0.3$ events are consistent with $L_{\rm X,\,true} \gtrsim 10^{44}$ (Berger et al. 2003). Thus, on average, subluminous GRBs appear to be more prevalent in the local universe.

Even though we cannot yet pinpoint the origin of this population, it is becoming apparent that subluminous GRBs must be physically different or extreme in properties relative to well-studied GRBs at higher redshifts ($z \gtrsim 0.3$). One explanation is that there is an alternative physical channel of stellar collapse that leads to subluminous bursts (e.g., Mazzali et al. 2006; Soderberg et al. 2006). The collapsing massive star might, for example, form a highly magnetized neutron star (Usov 1992; Thompson et al. 2004) rather than a black hole (MacFadyen & Woosley 1999). The greatest obstacle to proving alternative collapse channels for GRB production is the lack of observational signatures that would expose the central engine directly during the collapse.

A second possibility is that progenitor metallicity is what distinguishes subluminous events from their high-redshift counterparts (Woosley & Zhang 2007). At first glance, the sample presented in Figure 4 would seem to point in such direction, since subluminous events should be more prominent when the metallicity is higher, for example, at lower redshifts (Kewley & Kobulnicky 2005). As it turns out, however, there is little evidence supporting the evolution of progenitor properties as a function of redshift.

Perhaps the most obvious weakness lies with the incompleteness of the current GRB sample. It is worth stressing that the redshift trend in Figure 4 does not sample low-luminosity events at higher redshifts (Pian et al. 2006; Soderberg et al. 2006), and hence the current burst detection rate might bias the sample toward the more luminous events. Further we note that although the handful of low-redshift events appear to indicate a paucity of luminous GRBs in the local universe, their nondetection does not prove their demise with the current *Swift* detection rate of one subluminous burst per year (see § 5).

Additional complications arise from contradictory evidence regarding the metallicity of GRBs and their surroundings. For instance, a number of studies suggest a possible correlation between subluminous GRBs and low-metallicity hosts (Modjaz et al. 2007). In contrast, abundance estimates from afterglow spectra at $z \gtrsim 1.5$ allow the interstellar medium (ISM) surrounding the GRB event to reach solar metallicity (Prochaska 2006). One caveat is that the rotational energy budget prior to the GRB onset may be ultimately controlled by the iron abundance of the progenitor (Vink & de Koter 2005). Unfortunately, to the best of our knowledge, there are no conclusive identifications of iron or any other metal lines forged by the GRB progenitor (Mirabal et al. 2003; Sako et al. 2005). We conclude that at least two alternatives for subluminous burst production are broadly consistent with current measurements. As a result, the origin of subluminous GRBs remains unsettled.

5. CONCLUSIONS AND FUTURE WORK

The optical and X-ray observations of GRB 050826 we have presented confirm a general trend in which subluminous explosions dominate the local population ($z \lesssim 0.3$) of long-duration GRB events. Optical imaging reveals that the OT associated with GRB 050826 is located within an irregular, star-forming host galaxy with a rest-frame *B*-band luminosity $L_{\rm host} \approx 0.3L_*$. Together, these findings make the host galaxy of GRB 050826 an excellent target for high-resolution spectral studies at the site of the explosion.

In the quest to understand the origin of subluminous GRBs, it appears crucial to optimize future search strategies of subluminous GRBs at higher redshifts ($z \gtrsim 0.3$). In parallel, it would be prudent to explore numerically various afterglow observables as a function of accretion rate, and energy output from the central engine. This may lead to a better understanding of the link between the central engine and the afterglow luminosity distribution.

Lastly, a more complete analysis is still limited by the reduced number of low-redshift GRBs observed to date. We expect image subtraction techniques will play an important role in completing the census of subluminous GRBs in nearby galaxies. In particular, observations with future synoptic telescopes such as Pan-Starrs (Kaiser et al. 2002) and the Large Synoptic Survey Telescope (Tyson 2002) have the potential of detecting additional nearby bursts that might have been missed with the localization rate of GRB missions. Assuming a rate of subluminous events 230^{+490}_{-190} Gpc^{-3} yr^{-1} (Soderberg et al. 2006), a telescope cadence that covers a large portion of the available sky every three nights, and a limiting magnitude $V_{\rm lim} = 23.5$ shows that a dedicated synoptic telescope could discover 2553^{+5439}_{-2190} events as bright as GRB 060218/SN 2006aj (Mirabal et al. 2006) per year out to a maximum distance $D_{\rm max} = 3$ Gpc. Our results therefore suggest that current GRB/supernova rates could be enhanced by at least 2 orders of magnitude, should these exist. Such an improvement is likely to reshape GRB/supernova research dramatically.

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