LINKING SHORT GAMMA-RAY BURSTS AND THEIR HOST GALAXIES

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ABSTRACT
The luminosities of short-duration gamma-ray burst (SGRB) host galaxies appear to be anticorrelated with both the isotropic equivalent gamma-ray energy and the gamma-ray luminosity of the explosions, based on a sample of 12 bursts with host galaxy redshifts and photometry. The correlation does depend on the correct identification of the GRB 050509b host, but is otherwise robust. In particular, simple observational selection effects only strengthen the statistical significance of this correlation, from \( \sim 95\% \) to \( \sim 99\% \). The correlation may indicate that there are two physically distinct groups of SGRBs. If so, it requires that the more luminous class of explosions be associated with the younger class of progenitors. Alternatively, it could be due to a continuous distribution of burst and host properties, in which case it could be used as a crude SGRB distance indicator. As one possible explanation, we find that the effect of binary neutron star masses on inspiral time and energy reservoir produces a correlation of the appropriate sign, but does not automatically reproduce the correlation slope or the full range of SGRB energy scales.

If confirmed by larger samples, this correlation will provide a valuable new constraint on SGRB progenitor models.

Key words: gamma rays: bursts

1. INTRODUCTION

The host galaxies of short gamma-ray bursts (SGRBs; Kouveliotou et al. 1993) exhibit a wide range of physical properties. SGRBs have been found not only in star-forming hosts, but also in elliptical galaxies with strong upper limits on their star formation rate (hereafter “quiescent hosts”; Prochaska et al. 2006; Berger 2009). In contrast, long gamma-ray bursts (LGRBs) are found exclusively in star-forming galaxies (e.g., Le Floc’h et al. 2003; Fruchter et al. 2006; Savaglio et al. 2009). Several lines of evidence now link LGRBs with the deaths of massive stars (Hjorth et al. 2003; Stanek et al. 2003; Fruchter et al. 2006; Raskin et al. 2008). The origin of the SGRBs is not firmly established, but suspicion centers on merging neutron star (NS) binaries, or other phenomena primarily associated with neutron stars (Beczynski et al. 2006; Chapman et al. 2009). Hosts offer one of the best tools for unveiling the nature of the GRB progenitors, because the properties of the gamma-ray emission and afterglow are decoupled from many important details of the progenitor objects under the fireball model of GRBs (e.g., Paczynski & Rhoads 1993; Katz 1994; Piran 2005).

The situation is similar to supernovae (SNe), which divide into two groups, the Type Ia and the core-collapse events (which include Types II, Ib, and Ic). Core-collapse events are found only in star-forming galaxies, and are associated with the deaths of stars having initial masses \( \gtrsim 8 M_\odot \). In contrast, SNe Ia are found in both quiescent and star-forming hosts, and are thought to be powered by the nuclear explosion of a white dwarf whose mass is pushed above the Chandrasekhar limit by accretion. However, despite having a characteristic progenitor mass set by fundamental physics, the SNe Ia are not entirely homogeneous in their properties. Those found in star-forming hosts are both more frequent (per unit stellar mass) and more luminous than their cousins in quiescent galaxies (Hamuy et al. 1995; Scannapieco & Bildsten 2005; Sullivan et al. 2006).

In this paper, we look for similar trends linking the properties of SGRBs and their hosts. We find an anticorrelation between SGRB isotropic energy and host galaxy luminosity. We find no obvious selection effects that could produce such an effect, nor do we find evidence for any similar effect in a larger control sample of LGRBs.

2. OBSERVATIONS

We take our SGRB sample from the compilation by Berger (2009, hereafter B09) of all SGRBs localized by the X-ray telescope (XRT) on the Swift satellite (Gehrels et al. 2004). This sample contains 23 SGRBs, of which 12 have reported redshifts. These 12 form the core sample for our study. They are further divided into six with optical afterglows, and hence the most accurate positions and most secure host galaxy identifications (“sample 1” of B09), and six with somewhat less accurate positions based on X-ray data alone (“sample 2” of B09). The two subsamples are similar in most properties (B09).

We also form a comparison sample of 34 long bursts, by combining host galaxy information from Savaglio et al. (2009) with burst durations from the GCN circulars and other GRB properties from Amati et al. (2008).

To determine host galaxy rest-frame absolute \( V \)-band magnitudes \( V_{\text{abs}} \), we use host galaxy photometry from the literature. In the best cases, where detailed spectral energy distribution (SED) fits have been published, we measured the 5500 Å flux density directly from those fits (GRBs 050509b, 050709, and 050724 from Savaglio et al. 2009; GRB 070714b from Graham et al. 2009). In the least favorable cases, we do not have photometry bracketing the rest \( V \) band, and so extrapolated the reddest rest-wavelength photometry (from B09 for GRBs 061210, 060801, 061217, and 070724; and from Perley et al. 2007 for GRB 070429b) to 5500 Å using the SED for a continuous star formation model (Bruzual & Charlot 1993). The uncertainty in the absolute \( V \) magnitude associated with this extrapolation is of order 0.3–0.5 mag (small compared to the intrinsic scatter in the correlation presented in Section 3). Intermediate-quality cases were those where we have photometry in one filter very close to rest 5500 Å, or in two filters bracketing 5500 Å (GRB 051221a, from Soderberg et al. 2006; GRB 061006 and 071227, from D’Avanzo et al. 2009). In these cases, we either adopted the photometry in the closest filter or did a simple
interpolation of the two bracketing filters. Finally, for GRB 060801, I supplement the literature data with a new I-band measurement obtained by S. Malhotra in 2009 July using the Magellan I Baade telescope + IMACS. My photometry based on this image gives $I_{AB} \approx 22.7 \pm 0.3$ mag.

We then calculate host galaxy absolute magnitudes as $V_{\text{abs}} = m_{\text{AB}}(5500 \times (1 + z) \text{ Å}) - 5 \log(d_L/10 \text{ pc}) + 2.5 \log(1 + z)$. Here $z$ is the redshift, and $d_L$ is the luminosity distance, calculated assuming $H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_{0,m} = 0.27$, and $\Omega_{0,\Lambda} = 0.73$. We calculate the isotropic-equivalent gamma-ray energy $E_{\text{iso}}$ of the bursts directly from their fluence $f$ as $E_{\text{iso}} = 4\pi d_L^2 f/(1 + z)$. These quantities are summarized in Table 1, along with the burst durations, redshifts, and host galaxy star formation rates.

### 3. RESULTS

The isotropic-equivalent energy of the SGRBs is correlated with the absolute magnitudes of their host galaxies, with a correlation coefficient of 0.60. That is, the brightest bursts tend to occupy the least luminous hosts, and vice versa (Figure 1(a)). This is not expected from simple observational selection effects. If the samples are largely limited by flux and/or fluence, with most objects near the detection threshold, the range of distances in the sample should then lead to a positive correlation of burst energy with host luminosity. Such a positive correlation is seen for our control sample of LGRBs (Figure 1(b)).

The least luminous SGRBs are the closest, while the least luminous hosts span a wide range of redshifts. Gamma-ray sensitivity limits inclusion in our sample more critically than does sensitivity to the host galaxy’s starlight. If the host is not detected in the first relevant observation, more data can be taken, but if the GRB is not detected in the first observation, it can never enter the sample.

If a low-luminosity event such as GRB 050509B occurred in a subluminous host at $z \lesssim 0.5$, we should still see it. We see perhaps one such event, GRB 070724, which has low isotropic energy and luminosity, but lives in a star-forming host galaxy. We would also expect that if a highly luminous SGRB occurred in a large elliptical host galaxy, we should be able to observe such an event (and its luminous host) out to $z \gtrsim 0.8$. We see no such events. This suggests that the more luminous SGRBs are associated with young progenitors of some type that is absent in old elliptical galaxies.

We have tested the significance of the correlation in Figure 1(a) using a Spearman rank correlation test. The test yields a Spearman rank correlation coefficient of 0.54 for our

**Table 1**

| GRB ID  | Redshift $V_{\text{abs}}$ (AB mag) | $\log(E_{\text{iso}})$ (erg) | SFR ($M_\odot$ yr$^{-1}$) | $t_{90}$ (s) | References |
|---------|-----------------------------------|-----------------------------|---------------------------|-------------|------------|
| 050509b | 0.225                             | −23.27                      | 48.06                     | <0.1        | 0.04       | a          |
| 050709  | 0.161                             | −18.19                      | 49.24                     | 0.14        | 0.07       | a          |
| 050724  | 0.257                             | −22.11                      | 49.79                     | <0.05       | 3          | a          |
| 051221a | 0.546                             | −20.21                      | 50.96                     | 1.0         | 1.4        | b          |
| 060801  | 1.13                              | −20.65                      | 50.43                     | 6.1         | 0.5        | c, d       |
| 061006  | 0.438                             | −18.86                      | 50.83                     | 0.2         | 0.42       | e          |
| 061210  | 0.4095                            | −20.36                      | 50.66                     | 1.2         | 0.19       | c          |
| 061217  | 0.827                             | −19.61                      | 49.92                     | 2.5         | 0.21       | c          |
| 070429b | 0.903                             | −19.91                      | 50.13                     | 1           | 0.5        | f          |
| 070714b | 0.923                             | −18.26                      | 51.21                     | 0.4         | 3          | g          |
| 070724  | 0.4571                            | −21.08                      | 49.2                      | 2.5         | 0.4        | c          |
| 071227  | 0.381                             | −20.73                      | 49.93                     | n/a         | 1.8        | e          |

**Notes.** Selected properties of the primary SGRB sample used in this paper. Redshift, $t_{90}$, and star formation rates (SFRs) are taken directly from Berger (2009). $E_{\text{iso}}$ is derived from the SGRB gamma-ray fluence and redshift (again from B09) using a concordance (“WMAP”) cosmology (Spergel et al. 2007). The absolute V-band magnitude $V_{\text{abs}}$ is derived from published photometry plus (where necessary) a k-correction (described fully in Section 2). References for the photometry are given in Column 7, with labels indicating references as follows: (a) Savaglio et al. 2009; (b) Soderberg et al. 2006; (c) Berger 2009; (d) this work; (e) D’Avanzo et al. 2009; (f) Perley et al. 2007; (g) Graham et al. 2009.
set of 12 SGRBs. The corresponding one-sided significance level, derived from Monte Carlo measurements of Spearman rank correlations among uncorrelated random sequences with 12 entries, is 96.7%.

However, the true significance is higher, since observational selection effects work to produce the opposite sign of correlation. We have performed simple simulations of the correlation produced by observational selection in the absence of any true physical relation between the burst and host properties. We first constructed independent probability distributions for \( E_{\text{iso}} \), \( V_{\text{abs}} \), and \( z \). To these, we added selection probabilities based on gamma-ray fluence and host apparent magnitude. Each of these probability distributions was specified by a simple, plausible functional form. The functions were adjusted until the simulations were able to reproduce separately the one-dimensional marginal distributions of \( f \), \( E_{\text{iso}} \), \( R \), \( V_{\text{abs}} \), and \( z \) seen in the data (all within the Poisson uncertainties).

In each simulation, we constructed a “parent sample” of bursts, and applied the selection probabilities to simulate a “selected sample,” whose size is constrained to equal that of the observed sample. We then measure the correlation coefficient between \( E_{\text{iso}} \) and \( V_{\text{abs}} \) in the simulation. We repeat this procedure many times, and compare the distribution of simulated correlation coefficients to that measured in the observed sample, using both the conventional correlation coefficient and the Spearman rank coefficient.

Among \( 2 \times 10^3 \) simulations, only 2103 have conventional correlation coefficients above the observed value, and only 1072 have Spearman rank coefficients above the observed sample. Thus, by considering selection effects, we estimate the significance of the SGRB energy–host luminosity anticorrelation at about 98.9%–99.5%.

The specific functional forms adopted for the simulations were as follows. First, the simulated \( \log(E_{\text{iso}}/\text{erg}) \) was taken as a Gaussian with mean 47 and \( \sigma = 1.5 \) dex, truncated above at \( \log(E_{\text{iso}}/\text{erg}) = 51.3 \). The simulated redshifts were generated by a three-step algorithm: start with a uniform random variable between 0 and 2; if it is greater than 1, subtract a second uniform random variable between 0 and 1; and finally take the square root of the resulting random variable. This generates a distribution with \( 0 \leq z \leq \sqrt{2} \) that is substantially peaked toward redshift 1, like the observed redshift distribution. The host absolute magnitudes \( V_{\text{abs}} \) were taken as a Gaussian with mean \( V_{\text{abs}} = -20 \), \( \sigma = 1.5 \) mag, and truncated at a bright limit of \( V_{\text{abs}} = -23.5 \). (While the faint end of this distribution does not resemble a Schechter function, remember that the galaxy luminosity function should be weighted by galaxy luminosity or mass to find the expected distribution of GRB host luminosities under most reasonable progenitor models. This should result in either a centrally peaked distribution of host luminosity, or failing that, a rather flat faint end slope. Observationally, the extreme faint end behavior of the host luminosity distribution is poorly constrained by present data.)

For the simulated “observational selection” on GRB fluence \( f \), we took a detection probability that is piecewise linear in \( \log(f/\text{erg cm}^{-2}) \), with \( p = 1 \) for \( \log(f) \geq -6 \), \( p = 0.4 \) at \( \log(f) = -7 \), \( p = 0.05 \) at \( \log(f) = -8 \), and \( p = 0.0 \) for \( \log(f) \leq -9 \). For the “observational selection” on host brightness, we took a piecewise linear function in apparent \( R \) magnitude, with \( p = 1 \) for \( R \leq 21 \), \( p = 0.9 \) for \( R = 22 \), \( p = 0.65 \) for \( R = 23 \), \( p = 0.4 \) for \( R = 24 \), \( p = 0.2 \) for \( R = 25 \), \( p = 0.1 \) for \( R = 26 \), and \( p = 0 \) for \( R \geq 27 \). The overall probability of including a simulated burst in the simulated sample is the product of the selection probabilities on \( f \) and \( R \), and each simulated burst was kept or rejected from a simulated data set by comparing this overall probability to a uniform random number.

While the simulations include several ad hoc functional forms, they capture the essential points of any realistic model that does not have correlations between burst and host properties. First, the bursts and hosts span a wide range of intrinsic brightness. Second, the rate as a function of redshift could be matched by the volume element modified by some modest amount of rate evolution, out to the redshift where the simulated short bursts are too faint for detection. Third, the observational selection functions are monotonically decreasing over the range from the brightest to the faintest observed SGRBs and hosts. Fourth, the selection on the SGRB fluence excludes many more simulated events than does the selection on host luminosity. This induces a relatively weak correlation between host and burst brightness in the simulated samples. More strongly peaked intrinsic properties, or a more even balance between rejection by either GRB or host properties, would tend to induce stronger correlations in the simulated sample. Thus, plausible changes in our simulations should not strongly affect our conclusions.

Our results do depend substantially on GRB 050509b: if we exclude it from the sample, the remaining 11 observed points yield a Spearman rank correlation coefficient of 0.41. This corresponds to about a \( \sim 10\% \) chance based on our Monte Carlo simulations. GRB 050509b had no detected optical transient, and a relatively large error circle (998′ radius). However, its putative host is very bright, and the statistical probability of finding so bright a galaxy so close to a randomly chosen point on the sky is \( < 5 \times 10^{-5} \) (Bloom et al. 2006). This is similar to the chance that our observed correlation would occur by chance in a sample of 12 uncorrelated points. The other bursts without optical transients are less crucial than GRB 050509b, but removing all of them leaves a sample of only six SGRBs, which is then too small for the correlation to remain highly significant.

For reference, our control sample of LGRBs shows a correlation coefficient of \( \sim 0.54 \) between isotropic energy and host absolute magnitude. (For LGRB absolute magnitudes, we use the \( B_{\text{abs}} \) measurements from Savaglio et al. (2009).) We adapted our simulations to reproduce the marginal distributions of \( z \), \( R \), \( B_{\text{abs}} \), and so forth for the LGRB sample, and again compared the distribution of correlation coefficients to that observed for the LGRBs. Formally, this too yields a difference at the 99% level between the simulations and the data, here in the sense that the data show a stronger positive correlation between GRB and host brightness than do the simulations. Because the sign of the correlation matches the sign of the selection effects, and because the correlation is driven substantially by the X-ray flashes (020903 and 060218) at the bottom of the LGRB \( E_{\text{iso}} \) distribution, we do not attach great physical significance to this result yet. However, it is intriguing and may merit further investigation in future.

We also examined the relation between SGRB gamma-ray luminosity and host galaxy star formation rate per unit stellar mass (also called the specific star formation rate). Because the two most luminous SGRB hosts are early-type galaxies, with tight upper limits on their emission-line-derived star formation rate (Prochaska et al. 2006; Berger 2009; Savaglio et al. 2009), this plot clearly separates these two SGRBs from the rest of the sample. The specific star formation rate is defined as \( s = M_{\text{star}}/M_{\odot} \), where \( M_{\odot} \) is the star formation rate
and $M_\star$ is the stellar mass of the galaxy. However, lacking the data to fit an accurate stellar mass to some galaxies, we use the quantity $\log(S) = \log[M_\star/(M_\odot \text{ yr}^{-1})] + 0.4 V_{\text{abs}} = \log(s) + \log(M_\star/L_{\text{host}}) + \text{constant}$. To demonstrate the utility of $S$, we compared it to the published $s$ (from Savaglio et al. 2009) for the 34 LGRB hosts from our control sample. We find $\log(S) \approx 0.4 \log(s \times \gamma) - 7.9$, with a scatter of 0.3 dex (rms) that stems from variations in stellar mass to light ratio.

The results (Figure 2(a)) show that the separation of the SGRB hosts into actively star-forming galaxies and old stellar populations is accompanied by a separation of burst gamma-ray luminosity, with only the least luminous bursts found in the old hosts. The corresponding plot for LGRBs (Figure 2(b)) shows no correlations beyond the sample selection requirement that the least luminous events be reasonably nearby. A comparison of the two figures also shows the tendency (noted previously by, e.g., B09) for even star-forming SGRB hosts to have less vigorous star formation (i.e., lower $s$) than do LGRB hosts, and also the tendency for SGRBs to have lower gamma-ray fluxes.

4. DISCUSSION

While our sample is small, the anticorrelation between SGRB $E_{\text{iso}}$ and host luminosity is probably real, based on our Monte Carlo simulations. The similar anticorrelation between brightness of SNe Ia and the stellar population ages of their host galaxies was first described on the basis of a similarly small sample (13 SNe; Hamuy et al. 1995). We now examine possible interpretations for this result.

Suppose, first, that two distinct mechanisms produce SGRBs. Such a situation would arise naturally if two or more of the different proposed progenitors actually do produce SGRBs. Combinations that have been explored include coalescence of double neutron star binaries and of NS–black hole binaries (Belczynski et al. 2006; O’Shaughnessy et al. 2008; Troja et al. 2008), and combinations of NS–NS binaries with giant flares from magnetars (Chapman et al. 2009). Additionally, a range of SGRB properties might arise from NS–NS binaries alone, provided those binaries evolved through a range of different binary interaction histories (Belczynski et al. 2006; Salvaterra et al. 2008).

If one mechanism is associated with stars younger than 1 Gyr, and the other with ancient populations (age $\sim H_0^{-1}$), we can explain the properties of Figures 1(a) and 2(a). The fraction of old-progenitor SGRBs occurring in quiescent galaxies should match the fraction of stellar mass in quiescent galaxies. The present, limited data show two bursts in quiescent hosts, and a third similarly low-luminosity burst (070724) in a star-forming host galaxy. This matches well the fraction of stellar mass in elliptical galaxies at low redshift, which is 54%–60% (Baldry et al. 2004). Conversely, the fraction of more luminous SGRBs occurring in quiescent hosts is 0/9 in the present sample (Figure 2(a)). Under a two-population scenario, the mechanism responsible for the more luminous SGRBs should have a negligible rate for ages exceeding a few Gyr.

If instead there is a single, continuous distribution of SGRB and host properties, it suggests that the SGRB progenitor’s properties vary systematically with either age or metallicity, which vary systematically along the Hubble sequence and have direct effects on stellar-scale physics.

If SGRBs are due to binary neutron star inspiral events, an anticorrelation of SGRB energy and the specific star formation rate of the host galaxy could come from the dependence of inspiral time and available energy on mass. Gravitational radiation gives an inspiral time of

$$t_{\text{inspiral}} = \frac{5e^5}{256G^3 M_1 M_2 (M_1 + M_2)} a_0^4$$

(e.g., Landau & Lifshitz 1958), where $M_1$ and $M_2$ are the masses of the two bodies, $a$ is the semimajor axis of their orbit, and $G$ and $c$ are Newton’s constant and the speed of light, respectively. Thus, if a star formation event yields a population of compact object binaries with a range of mass, we expect a range of inspiral times. The SGRBs occurring in quiescent hosts would be those with low masses and/or wide initial separations. The available energy reservoir is $E \sim GM_1 M_2/R_{\text{final}}$, where $R_{\text{final}}$ is the characteristic size of the system when the GRB energy is released. If the SGRB event produces a black hole, we expect $R_{\text{final}} \sim R_{\text{grav}} \propto (M_1 + M_2)$, so that $E \sim M_1 M_2 c^2/(M_1 + M_2)$.

![Figure 2. Relation between GRB luminosity and the specific star formation rate of the host galaxy, for short (first panel) and long (second panel) GRBs. The least luminous SGRBs are the two in massive early-type host galaxies; their plotted points represent upper limits on specific star formation rate. While some bursts in star-forming hosts appear comparably faint (i.e., GRB 070724), we have yet to observe a bright burst in a quiescent host. For the LGRBs, there is no visible correlation of $L_\gamma$ and specific star formation rate. Point labels follow the same definitions as in Figure 1.](image-url)
Then, for $M_1 \approx M_2$, $t_{\text{inspiral}} \sim a_0^2 E^{-3}$. Characteristic stellar ages for SGRB hosts range from $\sim 10$ Gyr for quiescent hosts, to $\sim \tau^{-1} \sim 1$ Gyr for typical star-forming SGRB hosts (see, e.g., Savaglio et al. 2009). If this 10-fold range of age corresponds to a 10-fold range of $t_{\text{inspiral}}$, it would imply a range of $\sim 2\times$ in neutron star mass, which is comparable to the range of NS masses believed to exist in our Galaxy.

However, the corresponding $2\times$ range of energy cannot explain the range of $E_{\text{iso}}$ observed in Figure 1(a). A larger range in SGRB energetics might follow if $R_{\text{final}} \approx R_{\text{NS}}$, especially for a neutron star equation of state that gives $dR_{\text{fin}}/dM < 0$. Moreover, $a_0$ may correlate with $M_1$ and $M_2$ in some complex way depending on both binary star mass transfer and detailed supernova physics. While a more thorough understanding of the SGRB mechanism is clearly required before we can fully model the relation between host and SGRB properties, the existence of such a relation will provide valuable clues to the nature of the SGRBs.

The correlation in Figure 1(a) can also provide a tool for estimating SGRB redshifts, $\log(E_{\text{iso}})$ and $V_{\text{abs}}$ are related empirically by $\log(E_{\text{iso}}/\text{erg}) \approx 0.5044 + 0.75(V_{\text{abs}} + 20)$. Defining $D = d_{\text{L},\text{est}}/\sqrt{1 + z}$, so that $E_{\text{iso}} = (4\pi D^2) f$ and $V_{\text{abs}} = m_{\text{AB}}(0.55[1 + z] \mu \text{m}) - 5\log[(D/10 \text{ pc})]$, we can substitute for $E_{\text{iso}}$ and $V_{\text{abs}}$ to obtain a distance estimate:

$$\log(D_{\text{est}}/\text{Gpc}) = 0.063 + 0.130(m_{\text{AB}}(0.55[1 + z] \mu \text{m}) - 20) - 0.174\log(f_{\text{-6}}),$$

where $f_{\text{-6}}$ is the SGRB fluence in units of $10^{-6}$ erg cm$^{-2}$. The conversion from $D_{\text{est}}$ to the estimated distance $d_{L,\text{est}}$ and redshift $z_{\text{est}}$ must of course follow the cosmology we used to derive Equation (2), and the wavelength for the photometry should be performed at the rest $V$ band, which may require an iterative approach.

As an easier alternative, we can directly fit a relation of the form $\log(z_{\text{est}}) = \log(z_0) + a(R_{\text{AB}} - 20) + b \log(f_{\text{-6}})$ by minimizing $\Delta \log(z_{\text{rms}}) = (z_{\text{est}} - z_{\text{obs}})^2/(N - 1)^{1/2}$. This approach gives

$$\log(z_{\text{est}}) = -0.56 + 0.107(R_{\text{AB}} - 20) - 0.14\log(f_{\text{-6}}),$$

with residuals $\Delta \log(z_{\text{rms}}) = 0.14$ for our primary sample of 12 SGRBs. (For comparison, if we were to take $z_{\text{est}} = z = 0.55$, the corresponding rms is $\Delta z_{\text{rms}} = 0.31$, considerably larger. The reduction in residuals corresponds roughly to a probability 0.9996 that the two additional parameters in Equation (3) help improve redshift estimation compared to $z_{\text{est}} = $ constant, based on an $F$-test.) The redshift estimator in Equation (3) is formally independent of the adopted cosmological parameters, though it is less directly linked to whatever physical mechanism links $E_{\text{iso}}$ and $V_{\text{abs}}$. Differences between the predicted redshifts from the two equations are all much smaller than the scatter in either. The residuals from the fits substantially exceed the uncertainties expected from fluence and host magnitude measurements, implying that most of this scatter is intrinsic.

Figure 3 plots SGRB fluence measurements against host galaxy $R$ magnitudes from B09, and overplots the redshift lines derived from Equation (3).

Another possibility is that the external medium around SGRBs plays some role in their luminosity. The interstellar medium is typically less dense in elliptical galaxies than in actively star-forming galaxies. However, this should only affect the observed flux from external shocks that GRB ejecta drive into the ambient medium. External shocks are believed to power the afterglow emission, but not the GRB luminosity itself (e.g., Piran 2005). Since our observed anticorrelation involves the SGRB $\gamma$-ray flux itself, we disfavor this explanation.

To conclude, we have found an anticorrelation between the energy of an SGRB and the luminosity of its host galaxy. Such an anticorrelation occurs with a probability of $\sim 1\%$ in simulations that account for simple observational selection effects, and so is probably real. Its physical origin is unclear, though it is most likely due to a correlation between the age of an SGRB progenitor and the luminosity of the explosion. If this correlation is a continuous distribution, it can provide approximate redshift estimates for SGRBs. Time will tell whether this correlation holds for a larger sample, and whether it is a property of a single distribution, or if it instead reflects an underlying division of SGRBs into two physically distinct sets.

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