

A case of mistaken identity? GRB 060912A and the nature of the long – short GRB divide

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ABSTRACT

We investigate the origin of the GRB 060912A, which has observational properties that make its classification as either a long or short burst ambiguous. Short duration GRBs (SGRBs) are thought to have typically lower energies than long duration bursts, can be found in galaxies with populations of all ages and are likely to originate from different progenitors to the long duration bursts. However, it has become clear that duration alone is insufficient to make a distinction between the two populations in many cases, leading to a desire to find additional discriminators of burst type. GRB 060912A had a duration of 6 s and occurred only $\sim 10''$ from a bright, low redshift ($z = 0.0936$) elliptical galaxy, suggesting that this may have been the host, which would favour it being a short-burst. However, our deep optical imaging and spectroscopy of the location of GRB 060912A using the VLT shows that GRB 060912A more likely originates in a distant star forming galaxy at $z = 0.937$, and is most likely a long burst. This demonstrates the risk in identifying bright, nearby galaxies as the hosts of given GRBs without further supporting evidence. Further, it implies that, in the absence of secure identifications, “host” type, or more broadly discriminators which rely on galaxy redshifts, may not be good indicators of the true nature of any given GRB.

Key words: Gamma-ray bursts:

1 INTRODUCTION

Observations since the launch of Swift have finally begun to shed light on the nature of short duration GRBs (SGRBs - Kouveliotou et al. 1993). These observations demonstrate their apparent origin in populations of all ages (Gehrels et al. 2005; Hjorth et al. 2005a; Fox et al. 2005; Berger et al. 2005; Bloom et al. 2006) and, at lower redshift on average than the long duration bursts (Jakobsson et al. 2006a), now known to

originate in stellar core collapse (Hjorth et al. 2003; 2005b; Stanek et al. 2003). However, these observations have also emphasised the key issue of the distinction between long and short duration GRBs, as the two populations have significant overlap in many of their observed properties. Thus the task of accurately identifying a given burst as belonging to the long or short population is of particular importance.

Scientifically, the primary motivation for distinguishing between short and long GRBs (and indeed the true physical difference between the two subclasses of event) is the putative association of each class with a different mechanism for the production of the GRB. The difficulties in making this distinction are perhaps most strikingly illustrated by the

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low-redshift bursts GRB 060505 and 060614 which, while both exhibiting durations of >2 s, were not associated with bright supernovae, and may therefore represent another progenitor type (Fynbo et al. 2006; Gal-Yam et al. 2006; Della Valle et al. 2006; Gehrels et al. 2006).

Various possible criteria have been suggested for distinguishing what is truly a short population GRB (although perhaps the broader question is to identify which bursts may not be due to collapsars), these have been addressed by Donaghy et al. (2006). Of crucial importance are:

- *The sensitivity of the instrument making the detection and the energy range in which it operates.* For example, *Swift*/BAT operates primarily in the 15-150 keV range, which is softer than the 50-350 keV range where BATSE was most sensitive. As it is known that GRB emission lasts longer at lower energies (and also at higher sensitivities where the decay of the burst can be followed for longer) this needs to be taken into account. For example, the GRBs 050724 ($t_{90} = 3$ s) and 050911 ($t_{90} = 16$ s) would both have been classified as short duration GRBs when viewed by BATSE (Barthelmy et al. 2005; Page et al. 2006).

- *The spectral properties of the prompt emission.* Short bursts are (on average) spectrally harder than long bursts (Kouveliotou et al. 1993), thus hard γ -ray emission is a good diagnostic. Additionally short bursts show light curves which correlate well in all bands, while in long bursts the softer emission "lags" behind the harder emission (e.g. Norris & Bonnell 2006).

- *The properties of the host galaxy.* Long bursts occur primarily in sub-luminous blue star forming galaxies (e.g. Le Floc'h et al. 2003; Christensen et al. 2004; Fruchter et al. 2006). In contrast the suggested host galaxies of several short GRBs are bright elliptical galaxies at moderate redshift (e.g. GRBs 050509B and 050724 Gehrels et al. 2005; Bloom et al. 2006a; Berger et al. 2005), although some host galaxies are star forming (e.g. Fox et al 2005), or at much higher redshift (Levan et al. 2006b; Berger et al. 2006a). This has led to the suggestion that early-type host galaxies are a sufficient but not necessary indicator that a burst is of the short class.

- Based principally on GRB 050509B (Gehrels et al. 2005; Pedersen et al 2005) it has also been suggested that SGRBs may occur in greater numbers in galaxy clusters. Although further searches for clusters associated with SGRBs have found few other examples (e.g. Berger et al. 2006b), implying that (at the very least) the absence of a cluster cannot rule out an SGRB origin. Equally, relatively few searches for associated clusters have been conducted for LGRBs (see Levan et al. 2006c), and so the comparative properties remain poorly understood.

- *The energy of the burst, and presence of a supernova.* The long GRB population is now moderately well studied, with a large sample of redshifts and isotropic γ -ray energy releases. Equally, until recently, essentially all well studied LGRBs at $z < 1$ showed late time signatures plausibly associated with supernovae (e.g. Zeh et al. 2004). Deviations from these properties are obvious causes for interest, and may indicate a different population of bursts.

Here we consider the case of the intermediate duration ($t_{90} = 5.98 \pm 0.07$ s) burst GRB 060912A. The proximity of this burst to a bright, elliptical galaxy at $z = 0.0936$ led to speculation that this was the host (Berger 2006). Here we

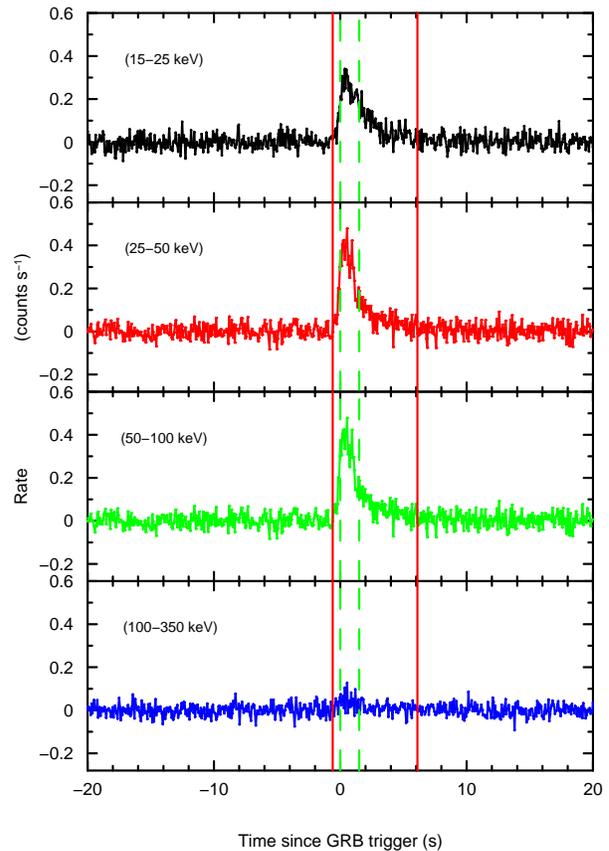


Figure 1. The BAT lightcurve of GRB 060912A in 4 energy bands (from top to bottom 15-25 keV, 25-50 keV, 50-100 keV, 100-350 keV). The t_{50} (dashed lines) and t_{90} (solid lines) durations are also shown.

present deep optical imaging and spectroscopy which was able to pinpoint the optical afterglow on the sky and demonstrate that the burst most likely originated at markedly higher redshift ($z = 0.937$). This illustrates the dangers of making such associations and may have interesting consequences for our view of short burst host identifications to date, most notably those of GRB 050509B (Gehrels et al. 2005; Bloom et al. 2006) and 060502B (Bloom et al. 2007).

2 OBSERVATIONS

GRB 060912A was detected by *Swift* at 13:55:54 UT on 12 September 2006 (Hurkett et al. 2006a). It exhibited a bright X-ray and optical counterpart at a location of RA= $00^h 21^m 08.16^s$ Dec = $+20^d 58' 17.8''$ (Hurkett et al. 2006b). The burst was also detected by the UVOT in all but the bluest (UVW2) band (Brown & Hurkett 2006). The BAT lightcurve in 4 bands is shown in Figure 1, with the t_{50} and t_{90} durations marked, we derive $t_{90} = 5.98 \pm 0.07$ s and $t_{50} = 1.98 \pm 0.05$ s. These values are somewhat longer than the typical values for BATSE short bursts ($t_{90} < 2$ s, $t_{50} < 1$ s; Kouveliotou et al. 1993), although recent observations of short bursts and a reanalysis of the duration distributions from BATSE bursts suggest that short population bursts can have $t_{90} > 2$ s (Donaghy et al. 2006; Zhang et al. 2007). The

burst was also detected by Konus-Wind in the 20-2000 keV energy range, and exhibited a duration of ~ 8 s (Golenetskii et al. 2006). The measured photon indices are 1.74 ± 0.09 for the BAT over the 15-150 keV range (Parsons et al. 2005) and 1.94 ± 0.2 from the Konus-Wind data in the 20-2000 keV range.

The location of the burst lies offset approximately $11.5''$ from a bright elliptical galaxy with $K = 13.2$. This galaxy was found to lie at $z = 0.0936$ and thus has $M_K \sim -25$, only marginally fainter than the cD galaxy found close to the location of GRB 050509B which had $M_K \sim -25.5$ (Gehrels et al. 2005).

We observed the location of GRB 060912A using the VLT and FORS1 on 14th September 2006. At the location of the optical afterglow (Hurkett et al. 2006a) we found a clearly extended source which we identified as the host galaxy of GRB 060912A (Levan et al. 2006a - see section 3.3 for further discussion on the allocation of the host galaxy). A image of the host galaxy is shown in Figure 2, while an enlarged field is shown in Figure 3. We subsequently obtained a spectrum of the host galaxy using the VLT and FORS2 on 21 September 2006. The spectrum exhibits a single, very strong emission line at 7219\AA , which we identified as [O II] (3727\AA) at a redshift of $z = 0.937$ (Jakobsson et al. 2006b); we also detected lines of [Ne III] and H γ at the same redshift, with a confidence of 8σ and 4σ respectively. An alternative explanation of the strong line is that it is due to H α at $z=0.0999$, however in this case additional weaker emission lines due to [NeIII] and H γ could not be explained. Additionally, given the strength of the emission line, the absence of bluer emission lines due to [O II], [O III] and H β would be surprising. The emission lines from [O II] and [Ne III] seen from the host of GRB 060912A are typical of the host galaxies of long duration GRBs (e.g. Bloom et al. 1998; Vreeswijk et al. 2001,2006). The equivalent width of the [O II] line is found to be 130\AA , amongst the largest EW seen in galaxies of comparable magnitude (e.g. Glazebrook et al. 1994). The total emission line flux is $F = 6.6 \times 10^{-17}$ ergs s $^{-1}$ cm $^{-2}$ and converting this to a luminosity, and subsequently a star formation rate using the method of Kennicutt (1998) implies $\text{SFR} = 4 M_{\odot} \text{ yr}^{-1}$ (formally a lower limit on the star formation since no extinction correction is possible)¹. Although there remained some afterglow contamination at the time of our spectroscopic observations, by subtracting a point source from the location of the afterglow we obtain an estimate of the host galaxy magnitude to be $R=22.0 \pm 0.5$ (the significant uncertainty stems from the afterglow subtraction). This corresponds to an absolute magnitude of $M_R \sim -21$, and is amongst the brightest GRB host galaxies (Fruchter et al. 2006). The offset of the GRB from the brightest region of the host galaxy is $\sim 0.3 \pm 0.1''$, corresponding to 2.3 ± 0.8 kpc, again typical of long GRBs (Bloom et al. 2002).

Additionally, when obtaining spectra of the host galaxy we aligned the slit such that two additional bright galaxies lay across it. These galaxies lie at RA = $00^h 21^m 05.5^s$, Dec = $+20^{\circ} 58' 18.1''$, and RA = $00^h 21^m 00.5^s$, Dec = $+20^{\circ} 58' 18.0''$ (see Figure 3). We identify these to be at $z = 0.0936$ and $z = 0.0977$, based on absorption lines from Ca

H&K, H β , H δ , [Mg I], [Na I], and the g-band. A previously catalogued source at RA = $00^h 21^m 19.1^s$, Dec = $+21^{\circ} 00' 25.00''$ has a redshift of $z = 0.0945$, making a total of at least 4 galaxies within $2'$ with similar redshifts, suggesting a foreground overdensity.

In order to search for putative X-ray emission from the cluster we summed the available XRT data taken in photon counting (PC) mode and extracted data in an annulus with inner and outer radii of 25-250 arcseconds. This allowed us to exclude the region containing significant flux from the afterglow. We additionally removed any other discrete sources contained within the annulus. No statistically significant excess emission is found within this annulus, and we place a limit of $F_X < 1.3 \times 10^{-14}$ ergs s $^{-1}$ cm $^{-2}$ (0.3-10 keV) and a corresponding limit on the X-ray luminosity of the putative cluster of $L_X < 2.8 \times 10^{41}$ ergs s $^{-1}$ (again in the 0.3-10 keV range), a factor of 10 less luminous than the cluster suggested to be associated with GRB 050911 (Berger et al. 2006b), this suggests that the observed overdensity of galaxies is due to a smaller group or cluster.

3 DISCUSSION

GRB 060912A had a duration of $t_{90} \approx 6$ s, which is near to the ≈ 5 s duration which Donaghy et al. (2006) find as the point of roughly equal probability of a given burst lying in either the long or short duration class (strictly this is an energy- and therefore instrument-dependent statement, and in this case appropriate for the harder response of BATSE). In such circumstances it is clearly necessary to rely on additional information to distinguish between the two populations. Previously it has been suggested that host type, total energy release and the presence of a supernova component can be useful in making this distinction (Donaghy et al. 2006), we investigate each of these in turn.

3.1 Nearby galaxies as an indicator of burst type

Host galaxy type is, on first sight an obvious means of distinguishing between long and short duration GRBs, since some short bursts are known to originate from elliptical galaxies (Berger et al. 2005), while long GRBs require current star formation. However, in many cases the level of significance of the association is rather low, at the 2-4 σ level (e.g. GRB 050509B: Gehrels et al. 2005; Bloom et al. 2006a; GRB 060502B: Bloom et al. 2007), thereby making the case for assigning a given burst to a host galaxy weaker, and significantly affecting the use of these galaxies as a proxy for burst type. A common problem for short burst afterglows is that they are often only detected due to the prompt *Swift* XRT observations. In these cases their locations on the sky are only accurate to $\sim 5''$. Although cross correlating with other sources can reduce this uncertainty to 2-3'' (e.g. Butler 2007) this still does not allow for the unambiguous identification of host galaxies that is possible via sub-arcsecond positions (Bloom, Djorgovski & Kulkarni 2002; Fruchter et al. 2006). This problem may be especially prevalent for S-GRBs, which, if due to compact object mergers may take place well away from the body of the host galaxy. The issue is well illustrated by Figure 3 which shows the XRT error circles for both GRB 060912A and GRB 050509B, which are

¹ Calculations have been performed assuming a Λ CDM cosmology with $\Omega_M = 0.27$, $\Omega_{\Lambda} = 0.73$ and $H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$

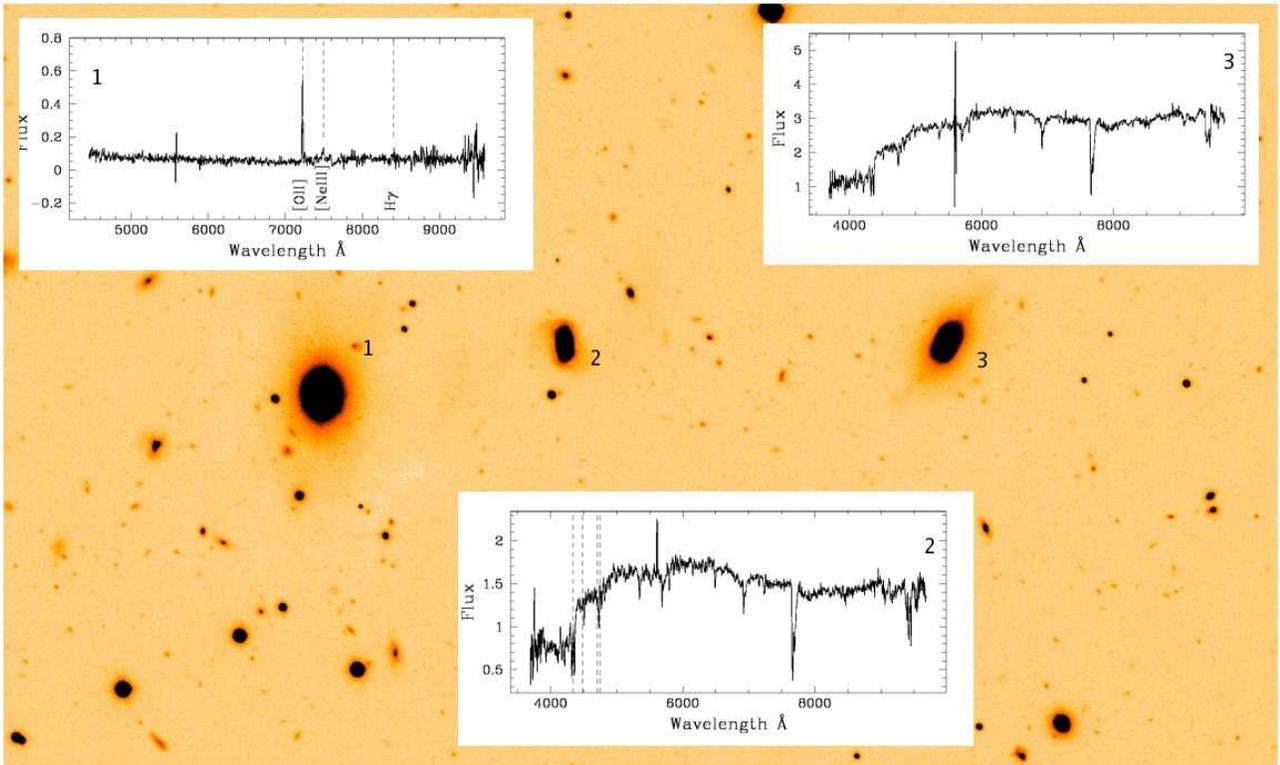


Figure 2. The region around GRB 060912A. The host galaxy is marked to the left of the 1. The individual galaxy spectra for the host galaxy and for two other cluster members are plotted as marked, the host galaxy is just to the left of the label. The flux units on the y-axis are 10^{-17} ergs s^{-1} cm^{-2} \AA^{-1} .

both located close to bright, low-redshift ellipticals, but as we have seen, in the former case the association is a chance alignment.

3.2 Energy and supernovae

Two further diagnostics suggested to distinguish between short and long GRBs are i) the presence of a supernova and ii) the energy of the burst. It has been suggested that SGRBs have, in some cases, much lower energy than long bursts. While no SGRB afterglow has exhibited any supernova signature, which are common in LGRBs. However, these two scenarios are also crucially dependent on secure redshifts, from either host galaxies, or preferably absorption lines. For example GRB 060912A would have an energy of $E_{iso} \sim 3 \times 10^{51}$ ergs, at $z = 0.937$, typical of long GRBs (e.g. Bloom et al. 2003), while at $z = 0.0936$ the energy release would have been only $E_{iso} \sim 3 \times 10^{49}$ ergs, more typical of the SGRB population (e.g. GRB 050724 Barthelmy et al. 2005; GRB 050709 Fox et al. 2005; Villasenor et al. 2005). Similarly, at $z = 0.0936$ any supernova would have been easily visible, with $R \sim 19$. However, at $z = 0.937$ its peak magnitude would have been $R \sim 25$, beyond the limits of most observations.

Therefore, in the absence of a secure redshift the true energy of the burst, and the expected properties of any supernovae are not assured, and cannot be used to make strong

constraints on which population it belongs to (this is illustrated in Figure 4).

These two constraints are further complicated by the fact that some S-GRBs apparently originate from much higher redshift, with correspondingly larger energies (e.g. GRB 050813, GRB 060121 and GRB 060313; Ferrero et al. 2006; Levan et al. 2006b; Berger et al. 2006a; Hjorth et al. in preparation) and the absence of supernova signatures in the apparently long duration GRBs 060505 and 060614 (Fynbo et al. 2006; Gal-Yam et al. 2006). Both of these factors may represent further interesting evidence of the overlap between short and long duration bursts. For example, it is possible that GRB 060505 and GRB 060614 originated from the same progenitors as short GRBs (e.g. Gehrels et al. 2006; Ofek et al. 2007), but with higher energy (Zhang et al. 2007). Alternatively these bursts might still be related to stellar core collapse without the release of sufficient radioactive material to create an observable supernova (e.g. all of the material has fallen directly onto the nascent black hole, Fryer et al. 2006).

3.3 Was GRB 060912A long or short population burst?

We conclude above that the likely host galaxy of GRB 060912A is a starforming galaxy at $z = 0.937$. This implies that the presence of a nearby elliptical is a chance alignment. However, the reverse is also possible (i.e. the chance

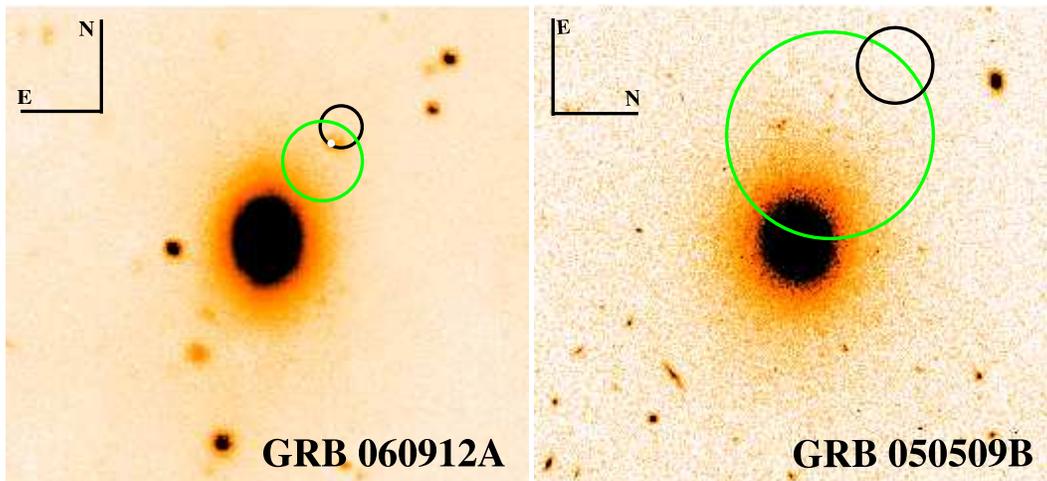


Figure 3. GRB 060912A and GRB 050509B. In each case the X-ray locations are marked, both the larger Swift-team XRT error circles and the smaller revised error circles of Butler (2007) in black. In the case of GRB 060912A the optical location is also shown in white. The image of GRB 060912A was taken on 14 September 2006 and shows some optical afterglow contribution on the host galaxy within the XRT error box. In the case of 050509B only an X-ray location was known, and, as can be seen in the deep HST observation in the right hand panel a large number of optical sources are visible within the error box, however none can be firmly associated with GRB 050509B. For GRB 060912A the precise optical position enabled the burst to be located on the host galaxy (visible within the XRT error box), which was subsequently shown to lie at $z = 0.937$. Both panels are plotted at the same physical scale, 1' on a side

alignment may actually be with the $z = 0.937$ galaxy). To ascertain the likelihoods for this we determine the probability of a random association as a function of X-ray error box size, host galaxy magnitude and host galaxy size. Following Bloom et al. (2002) we define a probability of a given GRB and galaxy being a chance association to be:

$$P_{i,ch} = 1 - \exp(-\eta_i), \quad (1)$$

where

$$\eta_i = \pi r_i^2 \sigma(\leq m_i), \quad (2)$$

and

$$\sigma(\leq m_i) = \frac{1}{3600^2 \times 0.334 \log_e 10} \times 10^{0.334(m_i - 22.963) + 4.320} \text{ galaxies/arcsec}^2. \quad (3)$$

This is based on the R-band number counts from Hogg et al. (1997), where m_i is the magnitude of the galaxy in question. Here r_i is the effective radius of a circle on the sky in which a given galaxy is found, and is a measure of angle subtended by the galaxy or (in the case of larger error localisations) by the errorbox of the GRB. Clearly this depends on the localisation confidence of the GRB, with $r_i = 2r_h$ (where r_h is the half light radius = $3''$ for the elliptical and $0.4''$ for the starforming galaxy) being suitable for most long GRBs which lie within the optical light of their hosts, $r_i = 3\sigma_i$ (where σ_i is the 1σ positional error) for large error boxes and $r_i = (4r_h^2 + R_0^2)^{0.5}$ for cases where the burst location lies well offset from the optical light of the galaxy (here R_0 is the offset of the burst position from the centre of the putative host). This approach enables us to consider *both* the uncertainty in the GRB position (which can be large in the case of XRT locations) and the physical size of the host

galaxy in question (e.g. nearby galaxies are brighter, and so therefore rare, but they also have larger angular sizes, increasing the probability of a chance alignment). The results of using this approach for both galaxies are shown in Table 1, which demonstrates the importance of small localisations, especially in the case of faint background galaxies.

The probability of chance alignments with the nearby elliptical galaxy and with a background galaxy are broadly equivalent (and indeed can show some variation based on bands used and alternative means of estimating r_i). One may then wonder why the higher redshift alternative is favoured. This can be understood in terms of our prior knowledge of the properties of the host galaxies of both long and short duration GRBs. Only a small sample of SGRBs have been linked to their hosts with high confidence, with no cases of absorption redshifts yet reported. So, while the suggestion that short bursts lie preferentially in older (elliptical) galaxies is certainly plausible it has not been demonstrated with high confidence, and the relative fraction found in such galaxies in poorly constrained (see e.g. Zheng & Ramirez-Ruiz 2006). In contrast LGRB hosts have been well studied for almost a decade and large samples now exist (e.g. Le Floch et al. 2003; Christensen et al. 2004; Fruchter et al. 2006). We know that these galaxies are usually very blue, with a range of irregular and compact morphologies (Conselice et al. 2005; Wainwright et al. 2006), and frequently show strong emission lines (e.g. Vreeswijk et al. 2001). We are therefore able to make stronger statements about the expected host galaxies of long bursts than short bursts. Indeed, assuming that the burst was long we would have broadly predicted *a priori* the properties of the $z = 0.937$ galaxy as its host. In other words the probability of the high redshift scenario assuming that the burst is long is much higher than the probability of the low redshift scenario assuming the burst is

| Galaxy | Error (") ^a | r_i (") | P_{chance} |
|---------|------------------------|-----------|--------------|
| G1 | 3.6 ^b | 12.1 | 0.007 |
| H | 3.6 ^b | 12 | 0.387 |
| G1 | 1.9 ^c | 13.7 | 0.009 |
| H | 1.9 ^c | 5.7 | 0.036 |
| G1 | 0.1 ^d | 12.1 | 0.007 |
| H | 0.1 ^d | 0.8 | 0.005 |
| 050509B | 9.3 ^b | ~11 | ~ 0.017 |
| 050509B | 3.4 ^c | ~18 | ~ 0.027 |
| 060502B | 5.4 ^b | ~17.5 | ~ 0.074 |
| 060502B | 3.7 ^c | ~17.5 | ~ 0.074 |

Table 1. Probabilities of chance alignment of GRB 060912A with both the nearby elliptical galaxy (G1) and the background (assumed host) galaxy at $z = 0.937$ (H). This is tabulated as a function of error box radius, demonstrating the importance of obtaining subarcsecond positions for afterglows, since high redshift galaxies are markedly smaller than an XRT error circle, which may contain several faint galaxies. The different probabilities correspond to different values of r_i which are relevant under the differing error box sizes and putative host assignments and are described in section 3.1.1. The different error radii correspond to i) the optical localisation, ii) The refined XRT team analysis and iii) The X-ray position of Butler (2007) refined based on cross-matched astrometry. In each case, following Bloom et al. (2002) we use the largest value for r_i based on the different means of its estimation described in section 3.1.1. For comparison and consistency the values for GRBs 050509B and 060502B are also calculated using the same approach, these numbers differ somewhat from those reported previously (e.g. Gehrels et al. 2005; Bloom et al. 2006) demonstrating the plausible range depending on the approach taken. ^a Errors are given at the 90% confidence level. ^b Error is given based on the refined analysis of the XRT data alone. ^c Error is determined by cross correlating the X-ray locations with other optical sources in the field, and is taken from Butler (2007). ^d Error is determined largely from the optical afterglow.

short (in Bayesian terms $P(H|L)$, where H is high redshift and L is long burst, is much higher than $(P(E|S)$ - where E is elliptical and S is short burst). An alternative approach would be to re-calculate the probabilities of chance alignments using, say, only galaxies which exhibit bright emission lines, although we do not do this here it is obvious that such a cut would significantly reduce the chance of random association with the $z = 0.937$ galaxy, and therefore we believe that our identification of it as the host of GRB 060912A is justified.

Although we argue above that the high- z origin of GRB 060912A is most likely, this discussion illustrates the difficulty of definitively linking some bursts to their hosts based only on proximity on the sky. In particular, had the host of GRB060912A been even fainter (as many long-burst hosts are), then it is possible that it would not have been discovered and the low- z scenario would have been favoured. All this highlights the importance of firmly linking a GRB to its host galaxy whenever possible, by ensuring that immediate deep observations are pursued to locate an afterglow, and *critically* also obtaining absorption redshifts for short bursts, which, due to the general faintness of the afterglows have so far not been obtained. In some cases it may be possible to constrain redshift photometrically, however, this is

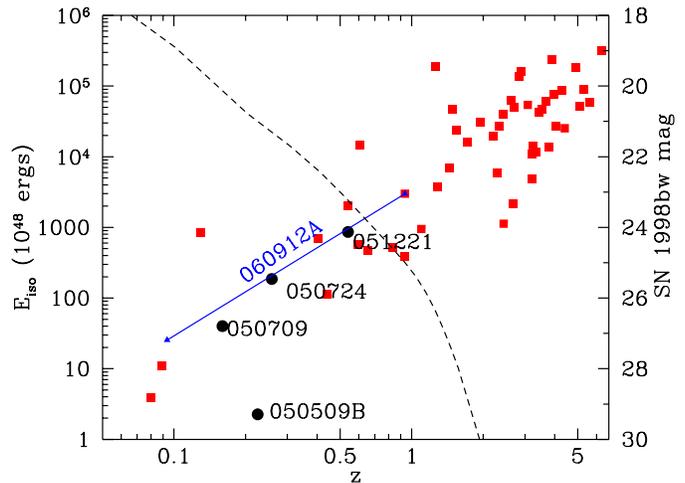


Figure 4. The redshift – energy – supernova degeneracy. Showing the energies (15-150 keV) and redshifts for *Swift* long and short bursts (long bursts squares, short burst circles). Also, showing the energy of GRB 060912A at its different possible redshifts. Any burst with unknown redshift will essentially move along a line of equal gradient. Therefore, as can be seen moving short bursts with low significance associations with nearby galaxies out to higher redshifts will result in energies comparable to the long duration bursts. Indeed several short bursts suggested to be at higher redshift (e.g. GRB 050813 (Ferrero et al. 2006), GRB 060121 (Levan et al. 2006b) and GRB 060313 (Hjorth et al in prep)) may already lie in this region. Additionally shown on the right hand axis and with the dashed line is the approximate R-magnitude of a supernova similar to SN 1998bw at maximum as it evolves with redshift. Beyond $z \sim 1.2$ it becomes essentially undetectable from the ground. Therefore, in the absence of a clear redshift identification neither energy, nor the absence of detectable supernova can place strong constraints on the nature of the burst.

only true for cases where the redshift is likely to be high enough that the Lyman- α break passes through one of the UVOT filters (or the optical). In the case of GRB 060912A (or in other bursts where hosts suggest $z < 1.5$) it is not possible to use photometric information to greatly constrain the redshift, or to determine between alternative possibilities.

3.4 Long – short overlap: Difficulties in defining a divide

The difficulties in deciding if a given burst belongs to the long or short GRB population have been one of the drivers for searching for additional constraints on the nature of the burst. However, as the sample of short GRBs remains small it is very dangerous to propagate the properties of the small number of bursts seen to date to the larger population, especially when several of the properties considered have been established only with marginal significance within the small population. We have discussed above the degeneracy that unknown redshift causes when considering the energy of the burst, the lack of supernova emission or even the nature of the host galaxy. However, these degeneracies also affect the prompt emission. Moving a given burst to higher redshift has two crucial effects. The first is that the burst duration

is time dilated by increasing redshift, while its spectrum is also softened (indeed high redshift was initially postulated as an origin for the very soft emission seen from X-ray Flashes (XRFs e.g. Heise et al. 2001)). The essence of this problem is therefore simple; *redshift can change the emission properties of short – hard bursts in to long – soft bursts*, further complicating any attempts to derive firm distinctions based on their observed prompt properties.

This effect may be present to differing degrees in the observed sample of GRBs since it depends on the redshift distribution of the two populations. If long and short duration bursts have the same redshift distribution then the effects of redshift can essentially be neglected. However, if short burst redshifts are typically low (e.g. Nakar et al. 2006), compared to long duration GRBs (Jakobsson et al. 2006a), then this effect may be significant. Therefore it is useful to consider how the GRB duration distribution may appear in the *rest-frame* of the bursts. This is shown in Figure 5, where the location of *Swift* bursts are shown as they were observed and as they would appear at zero redshift². The duration of the bursts in their rest frame has been shortened by a factor of $(1+z)$, however, at lower luminosity distance it is possible to track the emission out to late times, and therefore a factor of $(1+z)^{0.6}$ has been suggested by Donaghy et al. (2006), by not attempting to consider this relation here we essentially can examine a worst case scenario for the long-short duration overlap.

As can be seen in Figure 5, there are several long duration bursts, which, if viewed at lower redshift may have been classified as short duration bursts, these particular examples are GRB 050922C, GRB/XRF 050416, GRB/XRF 050406 and GRB 051016. Additionally prior to *Swift*, GRB 000301C at $z = 2.04$ exhibited a duration of $\sim 2s$ (Jensen et al. 2000) and GRB 040924 at $z = 0.857$ had $t_{90} \sim 2s$, although notably also exhibited a supernova (Soderberg et al. 2005).

These bursts demonstrate overlap in the burst population culled purely on duration. It may therefore be the case that we have observed a larger population of short duration bursts that is currently understood since the bursts may have been at higher redshifts, are not distinct energetically from long duration bursts, and lie at too great a distance for supernova searches to be attempted.

3.5 Spectral lag - another method for short – long discrimination?

The determination of which population a given burst belongs to remains of great importance and is an especially difficult task for bursts with moderately short durations ($t_{90} \sim 3 - 8s$) where there is most overlap between the two classes. In the case of GRB 060912A, the measured spectral lag of 190_{-40}^{+28} ms between the 5-25 and 50-100 keV bands and 83_{-43}^{+43} ms between the 25-50 and 100-350 bands placed the burst in long burst category, and, at early times following the burst suggested, apparently correctly, that the burst

should be classified as long (Parsons et al. 2006). This suggests, that *in cases where the duration of the burst is close to 2s* spectral lag may be a good means of discriminating between populations, with the advantage that it can be done rapidly, and based purely on the prompt emission properties (Norris & Bonnell 2006).

However, there may still be problems with the lag analysis in understanding the properties of the burst. Specifically, the primary aim of distinguishing the physical origin of the bursts. For example, while long bursts apparently follow a reasonably constrained lag-peak luminosity relationship (Gehrels et al. 2006), several of the GRBs most convincingly associated with supernovae (e.g. GRB 980425, 031203) lie off this empirical relation. Further GRB 060614 despite a duration of $> 100s$ also shows a low lag measurement. Does this imply that it really belongs to the same progenitor class as the short duration bursts? If so it would stretch the plausibility of compact binary mergers, since NS-NS mergers should be over very rapidly (e.g. Rosswog et al. 2002), while even for NS-BH mergers, which can show some extended emission due periods of mass transfer during the inspiral (Rosswog et al. 2004; Davies et al. 2005) may struggle to reproduce $>100s$ of high energy activity.

4 CONCLUSIONS

We have presented observations of GRB 060912A and its host galaxy. Although the burst occurred very close to a bright elliptical galaxy, lying within a group or cluster of galaxies at $z = 0.0936$ (the coincidence with the elliptical galaxy randomly has a probability of only 7×10^{-3}) we conclude that it more likely originated in an actively star forming galaxy at $z = 0.937$. The properties of the burst, and of its host galaxy at this redshift strongly suggest that GRB 060912A was a long duration burst, despite several lines initially pointing to a short population burst. This burst provides several important pointers for distinguishing between the long and short GRB population:

(i) *until* the properties of short burst hosts are better constrained by a larger sample of bursts we should be cautious in the assignation of host galaxies to nearby bright galaxies, and putative host should not be used as a strong indicator of burst type;

(ii) the difficulties in unambiguously identifying host galaxies, especially from X-ray only positions make the use of other proxies which rely on distance (e.g. supernova presence or total energy) unreliable.

(iii) If the true redshift distribution of short bursts is skewed to lower redshifts than for the long duration population then the overlap in rest-frame durations is larger, further blurring the distinction between long and short GRBs.

Notably however, a lag measurement demonstrated a positive lag and indicated accurately the true nature of this burst. Indeed, although lag measurements are also affected by cosmological time dilation the de-redshifted lag-luminosity relations are more robust (though not perfect) and may still allow distinction between different progenitor types.

Finally, it should be noted that the issue of distinguishing between different burst populations is not just one of

² Note that given the spectral range of the BAT the precise measurements of break energies in the prompt emission are not typically made, and therefore the bursts have been shifted assuming a single power-law

curiosity for pursuing followup observations, but is, in itself vital to constraining the nature and range of their progenitors. *Swift* observations are demonstrating that GRB populations are markedly more diverse than had previously been anticipated. This complicates the distinctions between them and implies that the long-short divide does not adequately describe all GRB populations. Attempting to simply place a burst in one of only two categories may inhibit, rather than enhance our knowledge of these still enigmatic transients. Indeed, it is cases of uncertainty (e.g. GRBs 060505, 060614 and 060912A) which may offer the best means of understanding the observed GRB populations.

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REFERENCES

- Barthelmy, S. D., et al. 2005, *Nature*, 438, 994
 Berger, E., et al. 2006a, *ArXiv Astrophysics e-prints*, arXiv:astro-ph/0611128
 Berger, E., Shin, M. -, Mulchaey, J. S., & Jeltama, T. E. 2006b, *ArXiv Astrophysics e-prints*, arXiv:astro-ph/0608498
 Berger, E. 2006, *GRB Coordinates Network*, 5568
 Berger, E., et al. 2005, *Nature*, 438, 988
 Bloom, J. S., Djorgovski, S. G., Kulkarni, S. R., & Frail, D. A. 1998, *ApJL*, 507, L25
 Bloom, J. S., Kulkarni, S. R., & Djorgovski, S. G. 2002, *AJ*, 123, 1111
 Bloom, J. S., Frail, D. A., & Kulkarni, S. R. 2003, *ApJ*, 594, 674
 Bloom, J. S., et al. 2006b, *ApJ*, 638, 354
 Bloom, J. S., et al. 2007, *ApJ*, 654, 878
 Brown, P. J., & Hurkett, C. P. 2006, *GRB Coordinates Network*, 5565, 1
 Butler, N. R. 2007, *AJ*, 133, 1027
 Christensen, L., Hjorth, J., & Gorosabel, J. 2004, *A&A*, 425, 913
 Conselice, C. J., et al. 2005, *ApJ*, 633, 29
 Brown, P. & Hurkett, C. 2006, *GRB Coordinates Network*, 5565
 Della Valle, M., et al. 2006, *Nature*, 444, 1050
 Donaghy, T. Q., et al. 2006, *ArXiv Astrophysics e-prints*, arXiv:astro-ph/0605570
 Davies, M. B., Levan, A. J., & King, A. R. 2005, *MNRAS*, 356, 54
 Ferrero, P., et al. 2006, *ArXiv Astrophysics e-prints*, arXiv:astro-ph/0610255
 Fox, D. B., et al. 2005, *Nature*, 437, 845
 Fruchter, A. S., et al. 2006, *Nature*, 441, 463
 Fryer, C. L., Young, P. A., & Hungerford, A. L. 2006, *ApJ*, 650, 1028
 Fynbo, J. P. U., et al. 2006, *Nature*, 444, 1047
 Gal-Yam, A., et al. 2006, *Nature*, 444, 1053
 Gehrels, N., et al. 2005, *Nature*, 437, 851
 Gehrels, N., et al. 2006, *Nature*, 444, 1044
 Glazebrook, K., Ellis, R., Colless, M., Broadhurst, T., Allington-Smith, J., & Tanvir, N. 1995, *MNRAS*, 273, 157
 Heise, J., in't Zand, J., Kippen, R. M., & Woods, P. M. 2001, *Gamma-ray Bursts in the Afterglow Era*, 16
 Hjorth, J., et al. 2003, *Nature*, 423, 847
 Hjorth, J., et al. 2005a, *Nature*, 437, 859
 Hjorth, J., et al. 2005b, *ApJL*, 630, L117
 Hogg, D. W., Pahre, M. A., McCarthy, J. K., Cohen, J. G., Blandford, R., Smail, I., & Soifer, B. T. 1997, *MNRAS*, 288, 404
 Hurkett, C. P., et al. 2006a, *GRB Coordinates Network*, 5558
 Hurkett, C. P., Page, K. L., & Rol, E. 2006b, *GRB Coordinates Network*, 5562
 Jakobsson, P., et al. 2006a, *A&A*, 447, 897
 Jakobsson, P., et al. 2006b, *GRB Coordinates Network*, 5617
 Jensen, B. L., et al. 2001, *A&A*, 370, 909
 Kennicutt, R. C., Jr. 1998, *ARA&A*, 36, 189
 Kouveliotou, C., Meegan, C. A., Fishman, G. J., Bhat, N. P., Briggs, M. S., Koshut, T. M., Paciesas, W. S., & Pendleton, G. N. 1993, *ApJL*, 413, L101
 Le Floch, E., et al. 2003, *A&A*, 400, 499
 Levan, A. J., et al. 2006a, *GRB Coordinates Network*, 5573
 Levan, A. J., et al. 2006b, *ApJL*, 648, L9
 Levan, A., et al. 2006c, *ApJ*, 647, 471
 Nakar, E., Gal-Yam, A., & Fox, D. B. 2006, *ApJ*, 650, 281
 Norris, J. P., & Bonnell, J. T. 2006, *ApJ*, 643, 266
 Ofek, E. O., et al. 2007, *ArXiv Astrophysics e-prints*, arXiv:astro-ph/0703192
 Page, K. L., et al. 2006, *ApJL*, 637, L13
 Parsons, A., et al. 2006, *GRB Coordinates Network*, 5561
 Pedersen, K., et al. 2005, *ApJ*, 634, L17
 Rosswog, S., Speith, R., & Wynn, G. A. 2004, *MNRAS*, 351, 1121
 Soderberg, A. M., et al. 2006, *ApJ*, 636, 391
 Vreeswijk, P. M., et al. 2001, *ApJ*, 546, 672
 Vreeswijk, P. M., et al. 2006, *A&A*, 447, 145
 Wainwright, C., Berger, E., & Penprase, B. E. 2005, *ArXiv Astrophysics e-prints*, arXiv:astro-ph/0508061
 Zeh, A., Klose, S., & Hartmann, D. H. 2004, *ApJ*, 609, 952
 Zhang, B., Zhang, B.-B., Liang, E.-W., Gehrels, N., Burrows, D. N., & Mészáros, P. 2007, *ApJL*, 655, L25
 Zheng, Z., & Ramirez-Ruiz, E. 2006, *ArXiv Astrophysics e-prints*, arXiv:astro-ph/0601622

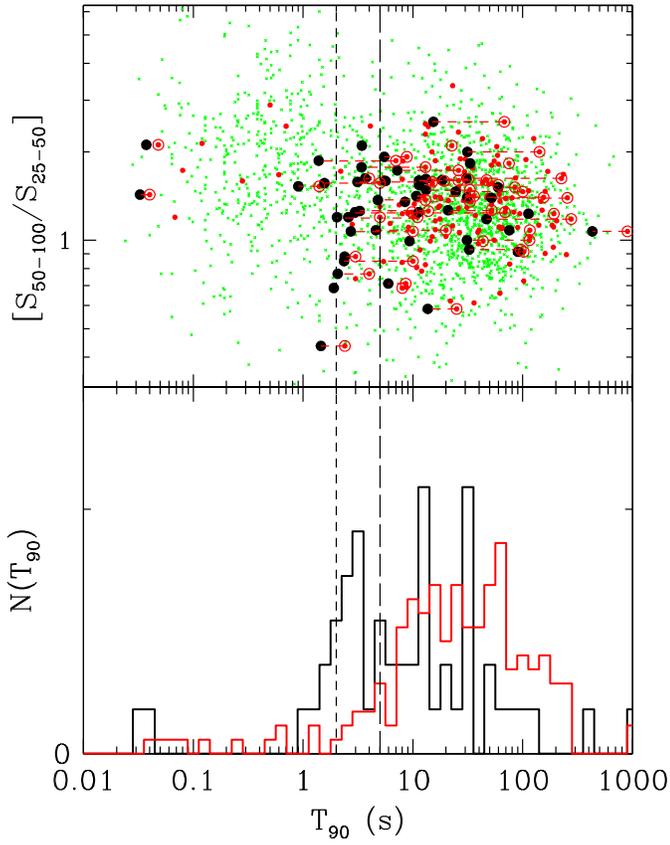


Figure 5. The hardness duration plot for GRBs detected by BATSE (green crosses) showing the short-hard (upper left) and long-soft (lower right) bursts. Overplotted are bursts observed by *Swift*, the small red circles represent all *Swift* bursts while the larger circles are those with redshifts. We have transformed the measured fluences into the BATSE passband assuming the best fitting spectral parameters reported in the GCN. black are the locations of the bursts *de-redshifted*, (i.e. as they would appear at zero redshift). As can be seen the corrections for the short bursts are generally small, while much larger corrections are necessary for the long bursts. Thus, the true duration distributions of the two classes of bursts have a substantially larger overlap than the observed ones. The two vertical lines show the canonical 2 second divide between long and short bursts, and the 5 second divide suggested by Donaghy et al. (2006). We do not attempt to compensate for the difference sensitivity of BAT compared to BATSE, and assume that the power-law behaviour in the spectra extends across a broad enough range that the redshift does not change the hardness ratio. In practice this is likely often not the case, and thus bursts appear softer at high redshift than they would at a lower redshift. As such this plot should be considered illustrative, rather than definitive. The lower panel shows a histogram of the durations of all *Swift* bursts (red line) and the de-redshifted durations of those with known redshifts.