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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 gamma-ray bursts (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 ∼10 arcsec 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 Very Large Telescope (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 gamma-ray bursts (GRBs) without further supporting evidence. Further, it implies that, in the absence of secure identifications, 'host' type, or more broadly discriminators that rely on galaxy redshifts, may not be good indicators of the true nature of any given GRB.

Key words: gamma-rays: bursts.

1 INTRODUCTION

Observations since the launch of *Swift* have finally begun to shed light on the nature of short-duration gamma-ray bursts (SGRBs; Kouveliotou et al. 1993). These observations demonstrate their apparent origin in populations of all ages (Berger et al. 2005; Fox et al. 2005; Gehrels et al. 2005; Hjorth et al. 2005a; 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 emphasized the key issue of the distinction between long-duration gamma-ray bursts (LGBRs) and SGRBs, 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 SGBRs and LGRBs (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 gamma-ray burst (GRB). The difficulties in making this distinction are perhaps

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most strikingly illustrated by the low-redshift bursts GRBs 060505 and 060614 which, while both exhibiting durations of >2 s, were not associated with bright supernovae, and may therefore represent another progenitor type (Della Valle et al. 2006; Fynbo et al. 2006; Gal-Yam 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 as follows.

(i) The sensitivity of the instrument making the detection and the energy range in which it operates. For example, *Swift*/BAT (Burst Alert Telescope) operates primarily in the 15–150 keV range, which is softer than the 50–350 keV range where Burst and Transient Source Experiment (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 SGRBs when viewed by BATSE (Barthelmy et al. 2005; Page et al. 2006).

(ii) The spectral properties of the prompt emission. Short bursts are (on average) spectrally harder than long bursts (Kouveliotou et al. 1993), thus hard gamma-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).

(iii) The properties of the host galaxy. Long bursts occur primarily in subluminous blue star-forming galaxies (e.g. Le Floc’h et al. 2003; Christensen, Hjorth & Gorosabel 2004; Fruchter et al. 2006). In contrast, the suggested host galaxies of several SGRBs are bright elliptical galaxies at moderate redshift (e.g. GRBs 050509B and 050724; Gehrels et al. 2005; Bloom et al. 2006; Berger et al. 2005), although some host galaxies are star forming (e.g. Fox et al. 2005), or at much higher redshift (Berger et al. 2006a; Levan et al. 2006c). 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.

(iv) 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. 2006b), and so the comparative properties remain poorly understood.

(v) 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 gamma-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, Klose & Hartmann 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 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 GRB 060502B (Bloom et al. 2007).

2 OBSERVATIONS

GRB 060912A was detected by *Swift* at 13:55:54 UT on 2006 September 12 (Hurkett et al. 2006a). It exhibited a bright X-ray and optical counterpart at a location of RA $= 00^{\mathrm{h}}21^{\mathrm{m}}08\overset{\mathrm{s}}{.}16$, Dec. $= +20^{\circ}58'17\overset{''}{.}8$ (Hurkett, Page & Rol 2006b). The burst was also detected by the Ultraviolet/Optical Telescope (UVOT) in all but the bluest (UVW2) band (Brown & Hurkett 2006). The BAT light curve in four bands is shown in Fig. 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 and $t_{50} < 1$ s; Kouveliotou et al. 1993), although recent observations of short bursts and a re-analysis 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. 2006) 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 arcsec 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).

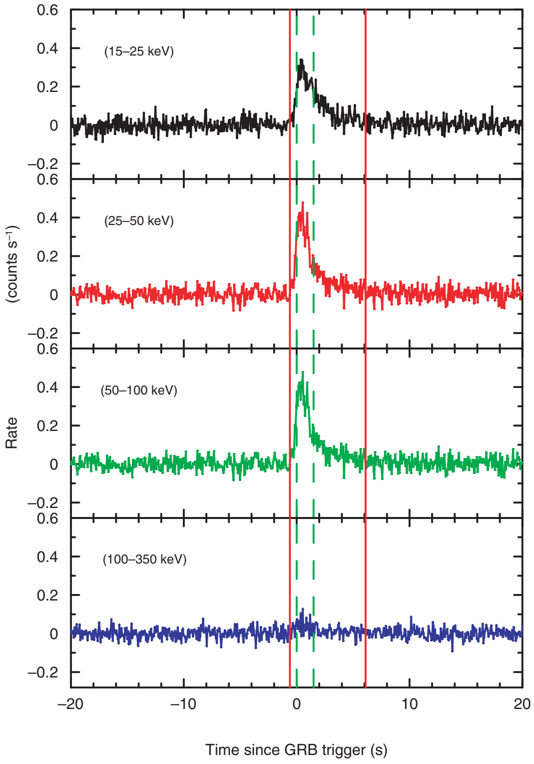

Figure 1. The BAT light curve of GRB 060912A in four energy bands (from top to bottom 15–25, 25–50, 50–100 and 100–350 keV). The t_{50} (dashed lines) and t_{90} (solid lines) durations are also shown.

We observed the location of GRB 060912A using the Very Large Telescope (VLT) and FORS1 on 2006 September 14. 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). An image of the host galaxy is shown in Fig. 2, while an enlarged field is shown in Fig. 3. We subsequently obtained a spectrum of the host galaxy using the VLT and FORS2 on 2006 September 21. The spectrum exhibits a single, very strong emission line at 7219 Å, which we identified as [O II] (3727 Å) at a redshift of $z = 0.937$ (Jakobsson et al. 2006b); we also detected lines of [Ne III] and Hγ at the same redshift, with a confidence of 8 and 4σ, respectively. An alternative explanation of the strong line is that, it is due to Hα at $z = 0.0999$, however, in this case additional weaker emission lines due to [Ne III] and Hγ 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 Hβ would be surprising. The emission lines from [O II]

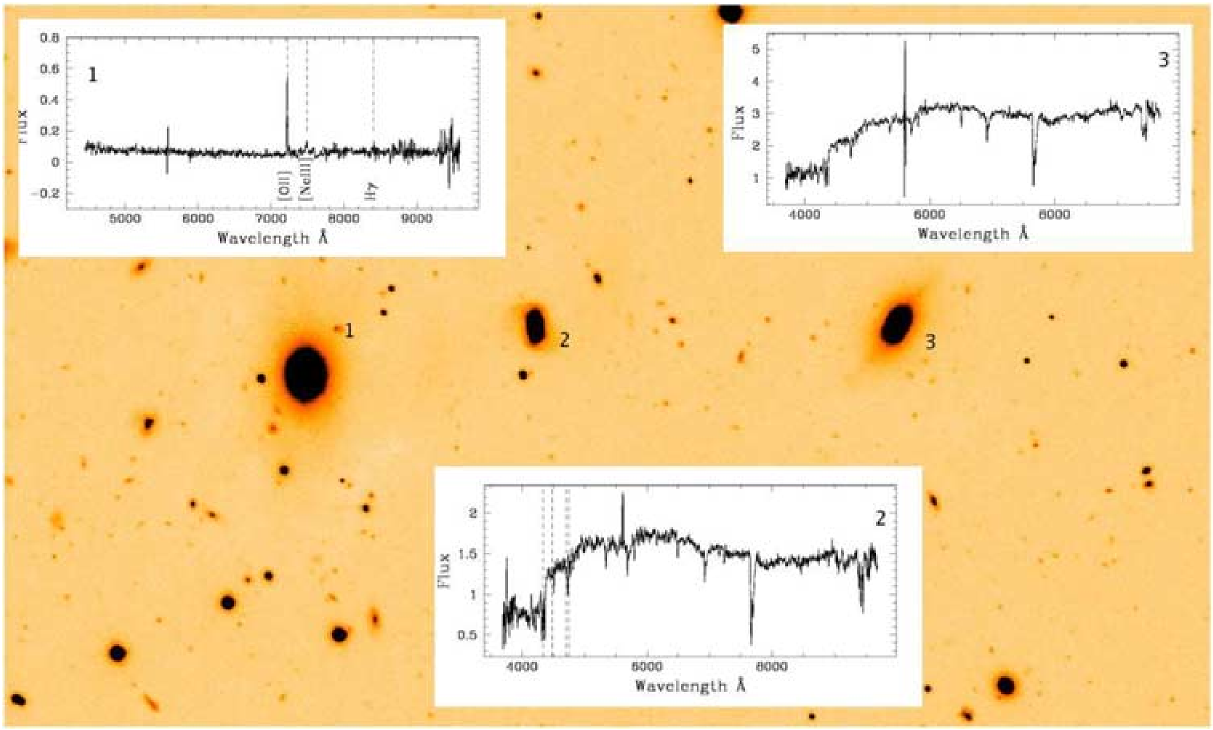

Figure 2. The region around GRB 060912A. The host galaxy is marked to the left of the 1. The individual galaxy spectra for the host galaxy and for two other cluster members are plotted as marked, the host galaxy is just to the left of the label. The flux units on the y-axis are 10^{-17} erg s^{-1} cm^{-2}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

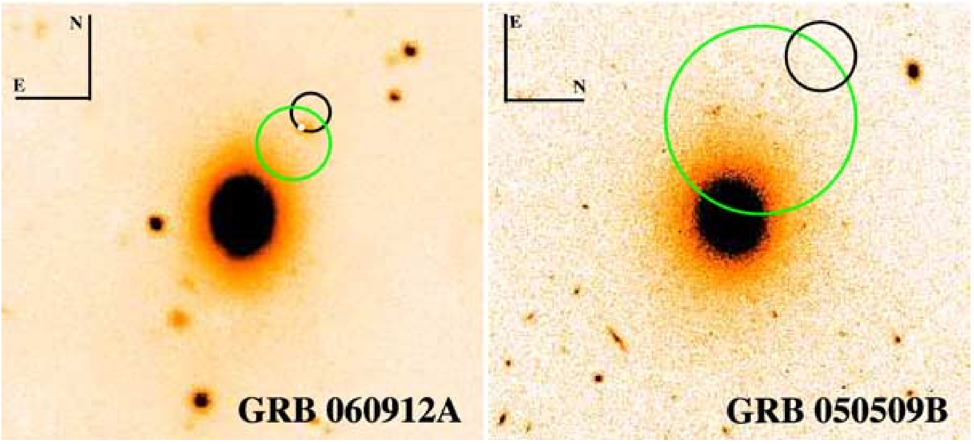

Figure 3. GRBs 060912A and 050509B. In each case the X-ray locations are marked, both the larger *Swift*-team XRT error circles and the smaller revised error circles of Butler (2007) in black. In the case of GRB 060912A the optical location is also shown in white. The image of GRB 060912A was taken on 2006 September 14 and shows some optical afterglow contribution on the host galaxy within the XRT error box. In the case of GRB 050509B, only an X-ray location was known, and, as can be seen in the deep *Hubble Space Telescope* (*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 arcmin on a side.

and [Ne III] seen from the host of GRB 060912A are typical of the host galaxies of LGRBs (e.g. Bloom et al. 1998; Vreeswijk et al. 2001, 2006). The equivalent width (EW) of the [O II] line is found to be 130 Å, amongst the largest EW seen in galaxies of comparable magnitude (e.g. Glazebrook et al. 1994). The total emission line flux is $F = 6.6 \times 10^{-17}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ and converting this to a luminosity, and subsequently an star formation rate (SFR) using the method of Kennicutt (1998) implies $\mathrm{SFR} = 4\,\mathrm{M_{\odot}\,yr^{-1}}$ (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 uncertainly 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 $\sim 0.3 \pm 0.1$ arcsec, corresponding to 2.3 ± 0.8 kpc, again typical of LGRBs (Bloom, Kulkarni & Djorgovski 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 = $00^{\mathrm{h}}21^{\mathrm{m}}05\overset{\mathrm{s}}{.}5$, Dec. = $+20^{\circ}58'18\overset{''}{.}1$ and RA = $00^{\mathrm{h}}21^{\mathrm{m}}00\overset{\mathrm{s}}{.}5$, Dec. = $+20^{\circ}58'18\overset{''}{.}0$ (see Fig. 3). We identify these to be at $z = 0.0936$ and 0.0977, based on absorption lines from Ca H&K, Hβ, Hδ, [Mg I], [Na I] and the g band. A previously catalogued source at RA = $00^{\mathrm{h}}21^{\mathrm{m}}19\overset{\mathrm{s}}{.}1$ and Dec. = $+21^{\circ}00'25\overset{''}{.}00$ has a redshift of $z = 0.0945$, making a total of at least four galaxies within 2 arcmin with similar redshifts, suggesting a foreground overdensity.

In order to search for putative X-ray emission from the cluster, we summed the available X-ray Telescope (XRT) data taken in photon counting (PC) mode and extracted data in an annulus with inner and outer radii of 25–250 arcsec. 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 $F_{\mathrm{X}} < 1.3 \times 10^{-14}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ (0.3–10 keV) and a corresponding limit on the X-ray luminosity of the putative cluster of $L_{\mathrm{X}} < 2.8 \times 10^{41}\,\mathrm{erg\,s^{-1}}$ (again in the 0.3–10 keV range), a factor of 10 less luminous that 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 LGBRs and SGRBs, since some short bursts are known to originate from elliptical galaxies (Berger et al. 2005), while LGRBs require current star formation. However, in many cases the level of significance of the association is rather low, at the 2–4σ 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 ∼5 arcsec. Although, cross-correlating with other sources can reduce this uncertainty to 2–3 arcsec (e.g. Butler 2007), this still does not allow for the unambiguous identification of host galaxies that is possible via subarcsec positions (Bloom et al. 2002; Fruchter et al. 2006). This problem may be especially prevalent for SGRBs, 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 Fig. 3 which shows the XRT error circles for both GRBs 060912A and 050509B, which are 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 SGRBs and LGRBs 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 $E_{\mathrm{iso}} \sim 3 \times 10^{51}$ erg at $z = 0.937$, typical of LGRBs (e.g. Bloom, Frail & Kulkarni 2003), while at $z = 0.0936$, the energy release would have been only $E_{\mathrm{iso}} \sim 3 \times 10^{49}$ erg, 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 Fig. 4).

These two constraints are further complicated by the fact that some SGRBs apparently originate from much higher redshift, with correspondingly larger energies (e.g. GRBs 050813, 060121 and 060313; Ferrero et al. 2006; Berger et al. 2006a; Levan et al. 2006c; Hjorth et al., in preparation) and the absence of supernova signatures in the apparently 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 GRBs 060505 and 060614 originated from the same progenitors as SGRBs (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 on to the nascent black hole; Fryer, Young & Hungerford 2006).

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[1] Calculations have been performed assuming a Λ cold dark matter (ΛCDM) cosmology with $\Omega_{\mathrm{m}} = 0.27$, $\Omega_{\Lambda} = 0.73$ and $H_0 = 71\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

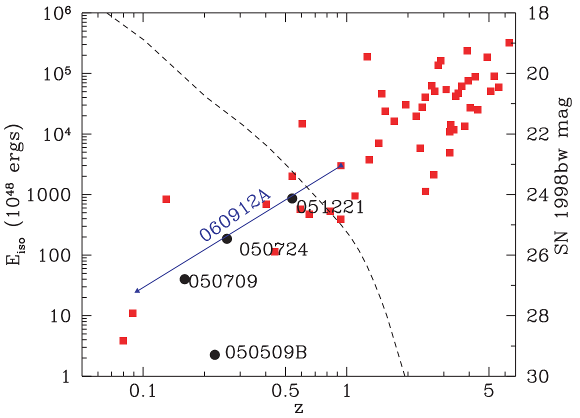

Figure 4. The redshift–energy–supernova degeneracy. Showing the energies (15–150 keV) and redshifts for *Swift*, long and short bursts (long bursts: squares; short burst: circles). Furthermore, showing the energy of GRB 060912A at its different possible redshifts. Any burst with unknown redshift will 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. 2006c; GRB 060313, Hjorth et al., in preparation) 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.

3.3 Was GRB 060912A long- or short-population burst?

We conclude above that the likely host galaxy of GRB 060912A is a star-forming 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 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

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

where

$$\eta_i = \pi r_i^2 \sigma(\leqslant m_i) \tag{2}$$

and

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

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 localizations) by the error box of the GRB. Clearly this depends on the localization confidence of the GRB, with $r_i = 2r_{\mathrm{h}}$ (where r_{h} is the half-light radius = 3 arcsec for the elliptical and 0.4 arcsec for the star-forming galaxy) being suitable for most LGRBs 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 $r_i = (4r_{\mathrm{h}}^2 + R_0^2)^{0.5}$ 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 localizations, especially in the case of faint background galaxies.

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 subarcsec 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 localization, (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.

Galaxy	Error (arcsec)[a]	r_i (arcsec)	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

[a] Errors are given at the 90 per cent 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.

The probability of chance alignments with the nearby elliptical galaxy and with a background galaxy is broadly equivalent (and indeed can show some variations 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 LGRBs and SGRBs. Only a small sample of SGRBs has been linked to their hosts with high confidence, with no cases of absorption redshifts yet reported. Thus, 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 Floc'h 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, Berger & Penprase 2005), 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 short [in Bayesian terms $P(H \mid L)$, where H is high redshift and L is long burst, is much higher than ($P(E \mid S)$, where E is elliptical and S is short burst]. An alternative approach would be to recalculate 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, if had the host of GRB 060912A 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 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 LGRB or SGRB population have been one of the drivers for searching for additional constraints on the nature of the burst. However, as the sample of SGRBs 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, Gal-Yam & Fox 2006), compared to LGRBs (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 Fig. 5, where the location of *Swift* bursts are shown as they were observed and as they would appear at zero redshift.[2] 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

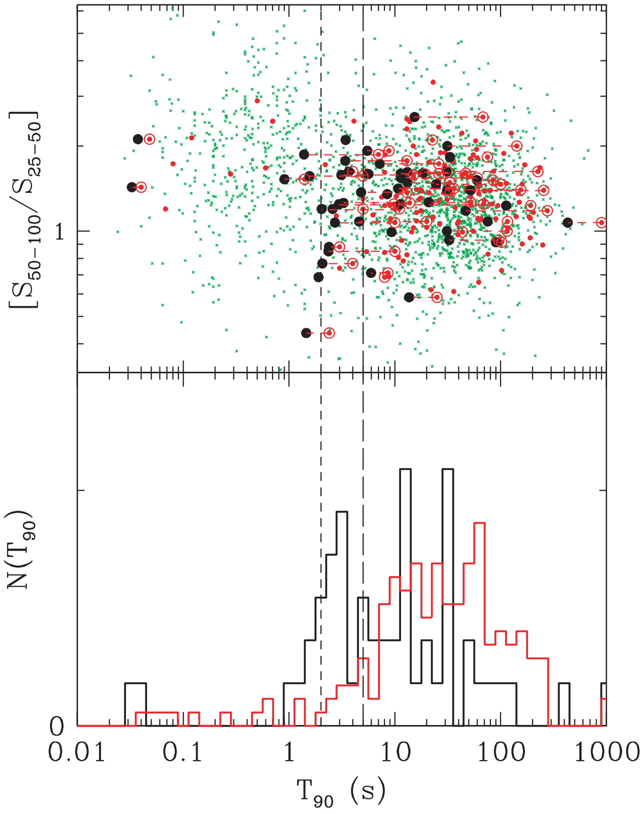

Figure 5. The hardness duration plot for GRBs detected by BATSE (green crosses) showing the short-hard (upper left hand) and long-soft (lower right hand) bursts. Overplotted are bursts observed by *Swift*, the small red circles represent all *Swift* bursts while the larger circles are those with redshifts. We have transformed the measured fluencies into the BATSE passband assuming the best-fitting spectral parameters reported in the GRB Coordinates Network (GCN). Black are the locations of the bursts deredshifted (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-s divide between long and short bursts, and the 5-s 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 deredshifted durations of those with known redshifts.

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[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.

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 Fig. 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 ∼2 s (Jensen et al. 2001) and GRB 040924 at $z = 0.857$ had $t_{90} \sim 2$ s, although notably also exhibited a supernova (Soderberg et al. 2006).

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 ($t_{90} \sim 3$–8 s) where there is most overlap between the two classes. In the case of GRB 060912A, the measured spectral lag of 190^{+28}_{-40} ms between the 5–25 and 50–100 keV bands and 83^{+43}_{-43} ms between the 25–50 and 100–350 keV 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 2 s 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. GRBs 980425 and 031203) lie off this empirical relation. Further GRB 060614 despite a duration of >100 s 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 (neutron star–neutron star) mergers should be over very rapidly (e.g. Rosswog et al. 2002), while even for NS–BH (black hole) mergers, which can show some extended emission due periods of mass transfer during the inspiral (Rosswog, Speith & Wynn 2004; Davies, Levan & King 2005) may struggle to reproduce >100 s 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 LGRB and SGRB population.

(i) Until the properties of short-burst hosts are better constrained by a larger sample of bursts we should be cautious, is 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 LGRBs and SGRBs.

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 deredshifted 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 curiosity for pursuing follow-up 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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