On the environment of short gamma-ray bursts

D. Kopáč, P. D’Avanzo, A. Melandri, S. Campana, A. Gomboc, J. Japelj, M. G. Bernardini, S. Covino, S. D. Vergani, R. Salvaterra and G. Tagliaferri

1 Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, SI-1000 Ljubljana, Slovenia
2 INAF-Osservatorio Astronomico di Brera, via Bianchi 46, I-23807 Merate (LC), Italy
3 Centre of Excellence SPACE-SI, Aškerčeva cesta 12, SI-1000 Ljubljana, Slovenia
4 INAF-IASF Milano, via E. Bassini 15, I-20133 Milano, Italy

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ABSTRACT
In this paper, we present a sample of ten short gamma-ray bursts (GRBs) with a robust redshift determination, discovered by the Swift satellite up to 2011 January. We measure their X-ray absorbing column densities and collect data on the host galaxy offsets. We find evidence for intrinsic absorption and no correlation between the intrinsic absorbing column density and the projected offset of the GRB from its host galaxy centre. We find that the properties in the gamma regime (T90, fluence and 1-s peak photon flux) of short GRBs with ‘bright’ and ‘faint’ X-ray afterglow likely disfavour different prompt emission mechanisms. The host galaxy offset and GRB duration (T90) do not correlate. Instead, there is a hint of anticorrelation between the effective radius normalized host galaxy offset and T90. Finally, we examine the properties of short GRBs with short-lived and long-lived X-ray afterglows, finding that some short GRBs with short-lived X-ray afterglows have their optical afterglow detected. In light of this, the X-ray afterglow duration does not seem to be a unique indicator of a specific progenitor and/or environment for short GRBs.

Key words: gamma-ray burst: general – X-rays: general.

1 INTRODUCTION
Gamma-ray bursts (GRBs) are cosmic explosions that release an extreme amount of energy in a very short time. As was already noticed in the 1980s (e.g. Norris et al. 1984) and became more obvious later, GRBs form two distinct populations (e.g. Kouveliotou et al. 1993): the short and long GRBs (SGRBs and LGRBs, respectively), defined at first approximation on the basis of the burst duration (SGRBs lasting less than ∼2 s in the observer frame), and likely corresponding to two different progenitors.

The merger 2009 of a double neutron star (NS–NS) or a neutron star–black hole (NS–BH) binary system is currently the leading model for SGRBs. The events predicted by this model (e.g. Eichler et al. 1989; Narayan, Paczynski & Piran 1992; Nakar 2007) are expected to have comparable time-scale and energy release to those observed in SGRBs. In such systems, the delay between binary formation and merging is driven by the gravitational wave inspiral time, which is strongly dependent on the initial system separation. Some systems are thus expected to drift away from the star-forming regions in which they formed, before merging takes place. Simulations (Belczynski, Bulik & Kalogera 2002; Belczynski et al. 2006) show that a large fraction of the merging events should take place in the outskirts or even outside the galaxies, in low-density environments. A much faster evolutionary channel has been proposed (Belczynski & Kalogera 2001; Perna & Belczynski 2002; Belczynski et al. 2006), leading to merging in only ∼106−107 yr, when most systems are still immersed in their star-forming regions. The above scenarios are based on ‘primordial’ binaries, i.e. systems that were born as binaries. Alternatively, a sizeable fraction of NS–NS systems may form dynamically by binary exchange interactions in globular clusters during their core collapse (Grindlay, Portegies Zwart & McMillan 2006; Salvaterra et al. 2008). The resulting time delay between star formation and merging would be dominated by the cluster core-collapse time and thus be comparable to the Hubble time (Hopman et al. 2006).

Merger scenario differs from the collapse of a massive star, which is believed to be associated with long-duration GRBs (LGRBs). These two types of progenitors produce different outcomes when exploding as GRBs. At variance with LGRBs, we have no ‘smoking gun’ (like supernova signatures) to identify the nature of the progenitors of SGRBs. However, SGRBs are distinguished from LGRBs not only by their duration, but also by other observed properties. If we consider the prompt emission, negligible spectral lag (Norris, Marani & Bonnell 2000; Norris, Scargle & Bonnell 2001) and hard spectra (Kouveliotou et al. 1993) are common for SGRBs. As opposed to LGRBs, for which the isotropic equivalent gamma-ray energy, Eγ,iso, is of the order of 1053 erg and for which the host

*E-mail: drejc.kopac@fmf.uni-lj.si
galaxies are typically dwarf galaxies with high star formation rate (Fruchter et al. 2006; Savaglio, Glazebrook & Le Borgne 2009), SGRBs are typically less energetic ($E_{\gamma,90}$ is of the order of $10^{49} - 10^{51}$ erg), they occur in both early- and late-type galaxies with lower star formation rate and are associated with an old stellar population (Nakar 2007; Berger 2009, 2011). Furthermore, SGRBs have been found to be inconsistent with the $E_{\gamma,90}$–$E_{\text{iso}}$ correlation (Amati 2006; Amati et al. 2007, 2008).

The afterglows of SGRBs tend to be significantly fainter on average than those of LGRBs (Kann et al. 2011). This is believed to be a consequence of the energetics and the surrounding environment (Nakar 2007). As shown in Campana et al. (2010), a powerful tool to characterize the GRB environment is the study of their X-ray absorbing column densities. By a systematic analysis of LGRBs with known redshift promptly observed by the Swift X-ray Telescope (XRT), Campana et al. (2010) found clear evidence that LGRB X-ray afterglows are heavily absorbed and occur in dense environments, as expected in the context of a massive stellar progenitor.

In this paper, we present a comprehensive analysis of the full sample of SGRBs with robust redshift determination, promptly observed\(^1\) by the Swift XRT up to 2011 January. For all these events, we derived the intrinsic X-ray column densities. Our findings are then compared to the results of Campana et al. (2010) obtained for LGRBs, with the aim of checking if the surrounding environment of these two classes of events is different and if this is perhaps related to the type of progenitor (as already discussed by Salvaterra et al. 2010), as well as to various SGRBs\(^2\) properties (redshift, duration, host galaxy offset and normalized host galaxy offset).

In Section 2, we present the analysis of X-ray data taken from the Swift XRT and describe how our sample was built. In Section 3, we perform various analyses on our sample and discuss the results. Summary and conclusions are given in Section 4.

Throughout the paper, we assume a standard cosmology with parameters: $H_0 = 71$ km s\(^{-1}\) Mpc\(^{-1}\), $\Omega_\Lambda = 0.73$, $\Omega_M = 0.27$.

2 DATA ANALYSIS

2.1 Sample selection

We collected the information on the $T_{90}$\(^2\) in the observer’s frame from the Swift Burst Alert Telescope (BAT) refined analysis GCN circulars,\(^3\) together with the properties in the gamma regime (spectral hardness and spectral lag) for all GRBs detected with the Swift BAT until 2011 January. We consider all GRBs classified as short in the Swift BAT refined analysis GCN circulars,\(^4\) where the additional properties in the gamma regime (apart from $T_{90}$), such as the lack of a spectral lag and the hardness ratio, are used to assess the short nature of a GRB. These criteria enable us to also include in our sample SGRBs with an extended emission (EE) for which $T_{90}$ can be well above 2 s. We selected the events observed by the Swift XRT and obtained a list of 60 SGRBs.

To exclude any observational biases, we checked the time delay between the BAT trigger and the start of the observations by the Swift XRT. We found that for 13 SGRBs the XRT observations started with significant delay of hours or even days after the BAT trigger due to observing constraints. We eliminated these SGRBs and ended up with 47 SGRBs. Among these, six had no X-ray afterglow detected and 17 had an X-ray afterglow too faint to perform any spectral analysis (see Section 2.2). Also these 23 SGRBs have been excluded from our analyses.

For the remaining 24 SGRBs (see Table 4 for the complete list), we retrieved the redshift information from the literature. We used only redshifts that are robust, meaning that an optical afterglow (OA) was detected and found to lie within the host galaxy’s light with a subarcsecond precision (so that the association between a host galaxy and a GRB is clear), and that the spectrum of the associated host galaxy was recorded. We obtained robust redshifts for 13 SGRBs, mainly from the GCN Circulars Archive or from published papers. We put the remaining 11 SGRBs to redshift $z = 0$, to extend our analysis on SGRBs’ intrinsic X-ray absorption with the obtained lower limits.

The sample of 13 SGRBs with robust redshifts also includes three GRBs for which the classification as a SGRB is still debated; GRB 060614 was a supernova-less GRB at $z = 0.125$ down to very deep optical limits, with spectral lag typical for SGRBs, but with a $T_{90}$ of 102 s and time-averaged spectral properties similar to LGRBs (Della Valle et al. 2006; Gehrels et al. 2006; Amati et al. 2007; Mangano et al. 2007). The possibility that this event is an SGRB with an EE was also suggested (Fynbo et al. 2006; Gal-Yam et al. 2006; Zhang et al. 2007). GRB 090426 can be classified as an SGRB based on its $T_{90}$, but the spectral and energy properties are more similar to those of LGRBs (Antonelli et al. 2009; Levesque et al. 2009; Ukwatta et al. 2009; Thöne et al. 2011). Similarly, GRB 100724A can be classified as an SGRB based on its $T_{90}$, but spectral lag and hardness of the spectrum point towards an LGRB classification (Ukwatta et al. 2010). Given the uncertainty in the classification, we do not also consider these three GRBs in our analyses and thus end up with 10 SGRBs with robust redshift determination.

Another selection criterion for SGRBs could be the inconsistency with the $E_{\gamma,90}$–$E_{\text{iso}}$ correlation (Amati et al. 2007), in which case one additional GRB could be considered short: GRB 060505 (see also McBreen et al. 2008; Ofek et al. 2007; Thöne et al. 2008; Xu et al. 2009). However, GRB 060505 was not observed promptly by the Swift XRT and so we did not include it in our analyses.

For the sake of simplicity throughout the paper, we name as Sample I the sample of 10 SGRBs with robust redshift determination (presented in Table 1) and as Sample II the sample of 11 SGRBs without robust redshift determination (presented in Table 2).

2.2 Sample analysis

In order to determine intrinsic absorption in X-rays for SGRBs, we performed a similar analysis to the one presented by Campana et al. (2010) for the LGRBs. We used the Swift XRT GRB light-curve repository (Evans et al. 2009). Because SGRBs have significantly fainter afterglows as opposed to LGRBs (Kann et al. 2011), it is sometimes impossible to get enough X-ray photons to perform any spectral analysis\(^4\). In addition, typical X-ray afterglow light curves have a multicomponent canonical shape and show

\(^1\) Within 150 s from the burst occurrence, and without the autonomous slew delay due to an observing constraint or due to a low merit value.

\(^2\) The time interval in which 90 per cent of the fluence in gamma-rays (in this case, in the 15–350 keV energy band) is detected.

\(^3\) http://gcn.gsfc.nasa.gov/gcn3_archive.html.

\(^4\) We required at least 200 counts with a constant 0.3–1.5/1.5–10 keV hardness ratio in the time interval that is specified in Table 1 and Table 2 to perform a spectral analysis and obtain the values of the intrinsic X-ray absorbing column density.
strong variability and spectral evolution especially at early times. We try to avoid taking data from this epoch and therefore we lose the brightest part of the afterglow. Based on these facts, we used data mostly from the photon counting (PC) mode, except for very dim afterglows, where we were also forced to use data from the window timing (WT) mode to increase our statistics by gathering enough X-ray photons. We analysed data only in time epoch where the 0.3–1.5 to 1.5–10 keV hardness ratio is constant, in order to prevent spectral changes that can affect the X-ray column density determination.

### Table 1. Properties of ten SGRBs with robust redshifts (Sample I). Columns are: GRB identifier, redshift, $T_{90}$, SGRB with an extended emission (EE), short-lived (SL) or long-lived (LL) X-ray afterglow (see Section 3.5), Galactic X-ray absorbing column density, X-ray spectrum exposure time and time interval, photon index ($\Gamma$), intrinsic X-ray absorbing column density, Cash’s C-statistic of the spectral fit (with the corresponding degrees of freedom), host galaxy offset, normalized host galaxy offset, references. All SGRBs have an optical afterglow (OA) detected. Redshifts are obtained from Berger (2009) and references therein, except for GRB 071227 (D’Avanzo et al. 2009), GRB 080905A (Rowlinson et al. 2010a), GRB 090510 (McBreen et al. 2010), GRB 100117A (Fong et al. 2011) and GRB 100816A (Tanvir et al. 2010). Errors are given at 90 per cent confidence level. UL indicates upper limits. For GRB references therein, except for GRB 071227 (D’Avanzo et al. 2009), GRB 080905A (Rowlinson et al. 2010a), GRB 090510 (McBreen et al. 2010), GRB references therein, except for GRB 071227 (D’Avanzo et al. 2009), GRB 080905A (Rowlinson et al. 2010a), GRB 090510 (McBreen et al. 2010), GRB

| GRB   | $z$  | $T_{90}$ (s) | EE | SL/LL | $N_{\text{H Gal.}}$ (10$^{21}$ cm$^{-2}$) | Exposure (interval) (ks) | $\Gamma$ | $N_{\text{H}}(z)$ (10$^{27}$ cm$^{-2}$) | C-statistic | Offset (kpc) | Normalized offset | References |
|-------|------|-------------|----|-------|----------------------------------------|--------------------------|--------|--------------------------------------|-------------|--------------|------------------|------------|
| 050724 | 0.257 | 3.0         | Yes | LL    | 14.0                                    | 22.0 (6000–10$^5$)       | 1.66$^{+0.15}_{-0.20}$ | 2.1$^{+1.5}_{-1.3}$ | 214.5 (279) | 2.54 ± 0.08 | 0.43 ± 0.02 | (a)         |
| 051221A| 0.546 | 1.4         | No  | LL    | 5.7                                     | 69.1 (6000–2 × 10$^5$)    | 2.10$^{+0.14}_{-0.10}$ | 2.2$^{+1.1}_{-1.1}$ | 260.4 (307) | 1.53 ± 0.31 | 0.30 ± 0.06 | (a)         |
| 061006 | 0.438 | 130.0       | Yes | LL    | 14.1                                    | 20.6 (150–10$^5$)        | 1.84$^{+0.28}_{-0.27}$ | <2.6 UL | 104.1 (170) | 1.44 ± 0.29 | 0.40 ± 0.08 | (a)         |
| 070714B| 0.923 | 64.0        | Yes | LL    | 6.4                                     | 25.9 (450–6 × 10$^4$)     | 1.97$^{+0.16}_{-0.15}$ | 2.8$^{+2.1}_{-2.1}$ | 283.6 (292) | 3.08 ± 0.47 | 0.78 ± 0.12 | (a)         |
| 070724A| 0.457 | 0.4         | No  | LL    | 1.2                                     | 0.024 (82–106)           | 1.51$^{+0.24}_{-0.23}$ | 5.5$^{+2.8}_{-2.5}$ | 161.9 (232) | 4.76 ± 0.06 | 1.12 ± 0.02 | (a)         |
| 071227 | 0.381 | 1.8         | Yes | LL    | 1.3                                     | 0.05 (90–140)            | 1.51$^{+0.16}_{-0.17}$ | 2.8$^{+1.3}_{-1.1}$ | 247.8 (330) | 14.8 ± 0.3  | 1.10 ± 0.03 | (b)         |
| 080905A| 0.122 | 1.0         | No  | –     | 9.0                                     | 0.39 (330–1230)          | 1.75$^{+0.56}_{-0.52}$ | <3.4 UL | 94.2 (76) | 18.1 ± 0.4 | –             | (a)         |
| 090510 | 0.903 | 0.3         | No  | LL    | 1.7                                     | 0.14 (100–240)           | 1.79$^{+0.16}_{-0.15}$ | 1.9$^{+1.5}_{-1.4}$ | 284.1 (315) | 7.8 ± 3.9  | 1.29 ± 0.65 | (c)         |
| 100117A| 0.915 | 0.3         | No  | SL    | 2.7                                     | 0.05 (105–155)           | 1.44$^{+0.22}_{-0.21}$ | 3.4$^{+3.0}_{-4.4}$ | 156.6 (215) | 0.47 ± 0.31 | –             | (d)         |
| 100816A| 0.805 | 2.9         | Yes | LL    | 4.5                                     | 16.1 (200–5 × 10$^6$)     | 1.90$^{+0.15}_{-0.13}$ | 2.3$^{+1.6}_{-1.5}$ | 273.7 (309) | 8.2 ± 2.3  | 0.64 ± 0.20 | (c)         |
SGRBs of Sample I, using public archival and proprietary ground-based imaging data. All SGRBs’ host galaxies were observed with the ESO-VLT, equipped with the FORS1/2 camera, with the exception of GRB 070714B (Gemini-N/GMOS data) and GRB 100816A (TNG/DOLORES data). Using the extended surface photometry tool of the GAIA6 package, we obtained the surface brightness profiles of eight SGRBs’ host galaxies. The obtained galaxy profiles were fitted with a S´ersic model:

\[ I(R) = I_e \times e^{-\left( \frac{R}{R_e} \right)^{1/n}}, \]

where \( n \) is the index indicating the profile curvature (\( n = 1 \) gives an exponential disc profile, \( n = 4 \) is the de Vaucouleurs profile), \( b_n \) is a dimensionless scale factor that can be approximated with \( b_n \sim 2n - \frac{1}{3} + \frac{4}{20n^2} + \frac{46}{255n^3} \) (Ciotti & Bertin 1999), \( R_e \) is the galaxy effective radius and \( I_e \) is the intensity at \( R = R_e \). For each fit, \( n, R_e \) and \( I_e \) were left free to vary. Host galaxy offsets and normalized host galaxy offsets for SGRBs of Sample I are provided in Table 1.

To check for various correlations, we used the Spearman rank correlation test throughout the paper. The uncertainties in the correlation coefficients were estimated with a simple Monte Carlo simulation, by taking into account the true errors using

\[ \text{value}_{\text{simulation}} = \text{value}_{\text{true}} + \epsilon \times \text{error}_{\text{true}}, \]

where \( \epsilon \) is a random number drawn from a normal distribution with zero mean and unit variance. With this method, we obtained 1000 simulated correlation coefficients for each set of values, and estimated the uncertainty on the original correlation coefficient as the standard deviation of simulated coefficients. Together with the correlation coefficient and its uncertainty, the \( p \)-value is also given.

3 RESULTS AND DISCUSSION

We were primarily interested in the study of the intrinsic X-ray absorption, and its correlations with \( T_{90} \), redshift, and particularly with the host galaxy offset and the normalized host galaxy offset. We extended our analysis with the discussion on the properties in the gamma energy band, on the SGRBs with an EE and on the short-lived (SL) and long-lived (LL) X-ray afterglows (defined in light of the X-ray flux measured at \( 10^4 \) s after the burst; see Section 3.5).

The study of these observables, which could be commonly obtained for SGRBs, provides the answer whether properties at high energies (such as \( T_{90} \), energetics and X-ray afterglow duration) are linked to the properties of the environment.

3.1 Intrinsic X-ray absorption

We first derived the intrinsic X-ray absorbing column densities, \( N_{H}(z) \), for the SGRBs belonging to Sample I. We obtained a measure for eight of them, while for two we obtained only upper limits (Table 1). Fig. 1 shows the distribution of \( N_{H}(z) \) for our whole sample. The distribution for the eight SGRBs with direct estimates of the intrinsic column density can be well fitted by a log Gaussian function, with a mean log \( N_{H}(z) = 21.4 \) and a standard deviation \( \sigma_{\log N_{H}(z)} = 0.1 \) (reduced \( \chi^2 \) of the fit is 0.4 with 2 dof). This shows that SGRBs are intrinsically absorbed.

Nevertheless, the mean log \( N_{H}(z) \) for SGRBs is on average lower than for the LGRBs from Campana et al. (2010), who reported a value of 21.9 with a standard deviation of 0.5. However, given the quoted error bars, the values are consistent. But it is noteworthy that the SGRBs from Sample I span in redshift up to \( \chi_{\text{max}}^{\text{GRBS}} = 0.923 \), so we are biased to lower redshifts when comparing \( N_{H}(z) \) values, since the LGRBs from Campana et al. (2010) span in redshift up to \( \chi_{\text{max}}^{\text{LGRBS}} = 8.1 \). To make a more appropriate comparison, we determined a mean log \( N_{H}(z) \) for LGRBs with \( z < 0.923 \) and \( z > 0.923 \) in the sample from Campana et al. (2010), obtaining a mean log \( N_{H}(z) < 0.923 \) = 21.5 with a standard deviation of 0.4 (reduced \( \chi^2 \) of the fit is 1.5) and a mean log \( N_{H}(z) > 0.923 \) = 22.0 with a standard deviation of 0.4 (reduced \( \chi^2 \) of the fit is 0.6), respectively. Thus, by limiting the analysis to \( z < 0.923 \), the mean \( N_{H}(z) \) of the LGRBs and the SGRBs from Sample I do not differ significantly.

To further investigate if the \( N_{H}(z) \) distributions of SGRBs and LGRBs are different, we used the two-sample Kolmogorov–Smirnov (K–S) test. We tested the distributions of eight SGRBs from Sample I and 85 LGRBs from Campana et al. (2010), obtaining the value of the K–S statistic \( D_1 = 0.70 \), with the corresponding probability that the two distributions are not drawn from different populations \( P_1 = 7 \times 10^{-4} \). Using the subsample of 14 LGRBs with \( z < 0.923 \) instead, we obtained \( D_2 = 0.52 \) and \( P_2 = 0.1 \), indicating that the two distributions are likely drawn from the same population. After the submission of this work, Margutti et al. (2012) independently reached similar conclusions on the intrinsic X-ray column density distribution of SGRBs.

Further confirmation that SGRBs are intrinsically absorbed is given by examining the Sample II. We noticed that even if we put these SGRBs to \( z = 0 \) and thus obtain the lower limits on the X-ray absorption, we get significant absorption in excess of the Galactic value (Table 2). These 11 lower limits are marked as black arrows in Fig. 1.

Having derived the intrinsic X-ray absorbing column densities, we checked if there is any dependence between \( N_{H}(z) \) and \( T_{90} \), and between \( N_{H}(z) \) and redshift, but there is no significant correlation. The Spearman correlation coefficients are \( \rho_{T_{90}}^{N_{H}(z)} = -0.11 \pm 0.36 \) (\( p = 0.80 \)) and \( \rho_{z}^{N_{H}(z)} = 0.14 \pm 0.35 \) (\( p = 0.73 \)), respectively. The uncertainties on the correlation coefficients are quite large, but this is expected given the large uncertainties on the values of \( N_{H}(z) \).
We checked if $N_H(z)$ correlates with the Galactic $N_H$ or with the photon index ($\Gamma$). We found no significant correlation, with the Spearman correlation coefficients being $\rho_{NH(Gal)} = -0.47 \pm 0.32$ ($p = 0.24$) and $\rho_{NH(z)} = -0.52 \pm 0.36$ ($p = 0.18$), respectively.

### 3.2 Intrinsic X-ray absorption and the host galaxy offset

For SGRBs from Sample I, we can investigate if there is any correlation between $N_H(z)$ and the host galaxy offset. Fig. 2 shows $N_H(z)$ versus host galaxy offsets and $N_H(z)$ versus normalized host galaxy offsets.

We tested the possible correlations between (normalized) host galaxy offsets and $N_H(z)$ using the Spearman rank correlation test for Sample I, excluding the two SGRBs that have only upper limits on $N_H(z)$. For host galaxy offsets versus $N_H(z)$, the Spearman correlation coefficient is $\rho_{offsets} = -0.07 \pm 0.36$ ($p = 0.87$). For normalized host galaxy offsets versus $N_H(z)$, the Spearman correlation coefficient is $\rho_{norm\_offsets} = 0.20 \pm 0.35$ ($p = 0.67$). If we exclude GRB 070724A and GRB 071227, because the lower limits on their normalized host galaxy offsets are larger than 1 (this would indicate that a GRB occurs outside of its host galaxy, if characterized by the effective radius), the Spearman correlation coefficient is $\rho_{norm\_offsets} = -0.10 \pm 0.47$ ($p = 0.95$). All values indicate that there is no significant correlation. The uncertainties on the correlation coefficients are large due to large uncertainties on the values of $N_H(z)$ and (normalized) host galaxy offsets (see Fig. 2).

For normalized host galaxy offsets, which indeed better represent the relative location of a GRB inside its host galaxy, one would expect that (especially when smaller than 1) they will be inversely correlated with $N_H(z)$. This would indicate that the more we go towards the edge of the galaxy, the less intrinsic absorption we have, i.e. the environment gets less dense. We obtained no such result. The reason could be either the large errors or that here we are dealing with projected offsets, which do not give us any information about the position of a GRB in its host galaxy along the line of sight. For the same projected offset, a GRB can occur closer or further away from us in its host galaxy, resulting in less or more intervening host galaxy material along the line of sight. Such effect is of course less strong near the edges of the galaxies, as is likely the case of GRB 071227, for which an OA position falls at the very edge of the galaxy disc (D’Avanzo et al. 2009).

Furthermore, we note that the above analysis is probably affected by some selection effect against large offsets [and likely lower $N_H(z)$] because, in order to have events with robust redshift, the SGRBs of Sample I include only events with positional coincidence between the OA and the host galaxy light (see Section 2.1).

### 3.3 X-ray afterglow brightness and the properties in the gamma regime

As pointed out in Sections 2.1 and 3.1, 44 SGRBs promptly observed by the Swift XRT can be divided into two classes, according to the brightness of their X-ray afterglow. Almost half of them have X-ray afterglow bright enough to perform X-ray spectroscopy (they have at least 200 counts with a constant 0.3–1.5/1.5–10 keV hardness ratio in the specified time interval), while the other half have too faint X-ray afterglow, and thus no spectroscopic study could be performed. Moreover, among the “faint” SGRBs, six events (i.e. 14 per cent of the whole sample or 26 per cent of the “faint” SGRBs’ sample) have no X-ray afterglow detected, in spite of the prompt Swift XRT follow up. This is at variance with respect to the LGRBs, where for ~95 per cent of the events promptly observed by the Swift XRT an X-ray afterglow is detected (Evans et al. 2009). Such a modality in the X-ray afterglow brightness can be explained by the differences in the GRB energetics (with more energetic GRBs having brighter afterglows) or in the density of the circumburst medium (with GRB exploding in denser environments having brighter afterglows).

In order to check if these two classes of SGRBs show any significant difference in their prompt emission properties, we computed their distribution of fluence, 1-s peak photon flux and $T_{90}$, measured by the Swift BAT, and compared them with a two-sample K–S test. As can be seen in Table 4, SGRBs with brighter X-ray afterglows seem to have, on average, higher fluences, peak fluxes and longer durations. The probabilities associated with the K–S tests for each distribution is of the order of a few percent (see Table 3, upper part), likely suggesting that the two classes of SGRBs have different prompt emission properties. However, the presence of eight SGRBs with an EE (GRB 050724, GRB 051227, GRB 061006, GRB 070714B, GRB 071227, GRB 080123, GRB 080503 and GRB 100816A) introduces some biases in this study. In particular, SGRBs with an EE can spuriously increase the average value of...
being indicative of different progenitors. A possible theoretical explanation would be that we are dealing with two distinct NS–NS or NS–BH populations. The events showing brighter X-ray afterglows might be associated with primordial double compact object systems merging in a relatively short time (and thus occurring inside their host galaxies, in star-forming environments; Perna & Belczynski 2002), while the events with fainter X-ray afterglows might be originated by double compact object systems which experienced a large natal kick or which are dynamically formed in globular clusters (associated with a low-density environments; see Section 1).

On the other hand, we note that the values of $T_{90}$, fluence and 1-s peak photon flux reported in Table 4 are measured in the observer’s frame. It has not been possible, due to the lack of redshift measurement for many SGRBs, to transform these values to the GRB’s rest frame, especially for SGRBs with faint X-ray afterglow. This may again introduce some bias, especially for SGRBs that would occur at high redshift (Berger et al. 2007).

### 3.4 SGRBs with an EE

To investigate if the SGRBs with an EE from Sample I lie on average closer to the centre of their host galaxies (as presented first by Troja et al. 2008), we plotted in Fig. 3 the $T_{90}$ values versus host galaxy and normalized host galaxy offsets. The value of $T_{90}$ somehow indicates the duration of a GRB, and SGRBs with an EE have on average larger $T_{90}$ than SGRBs without an EE. Calculating the Spearman rank correlation coefficient between $T_{90}$ and host galaxy offsets, we obtain $r_{s} = -0.13 \pm 0.10$ ($p = 0.73$). This

### Table 3. Results of the two-sample K–S test from comparing $T_{90}$, fluence and 1-s peak photon flux distributions between ‘bright’ (Samples I and II) and ‘faint’ X-ray afterglow samples. The upper part shows the results for all SGRBs, while the lower part shows the results for SGRB without an EE (see Table 4). $D$ represents the calculated value of the K–S statistic and $P$ is the corresponding probability that two distributions are not drawn from different populations.

| Distribution | $D$  | $P$  |
|--------------|------|------|
| All SGRBs    |      |      |
| $T_{90}$     | 0.43 | 0.02 |
| Fluence      | 0.43 | 0.02 |
| 1-s peak flux| 0.31 | 0.20 |
| SGRBs without an EE |      |      |
| $T_{90}$     | 0.40 | 0.09 |
| Fluence      | 0.30 | 0.34 |
| 1-s peak flux| 0.30 | 0.36 |

We thus repeated the K–S tests excluding the events showing an EE. We find that the associated probabilities increase, suggesting that the two classes of SGRBs do not show significant differences in their prompt emission properties (see Table 3, lower part).

The different brightness of their X-ray afterglows might thus be a consequence of the density of the environment around the GRB and fluence and $T_{90}$. The different brightness of their X-ray afterglows might thus be a consequence of the density of the environment around the GRB and $T_{90}$. We thus repeated the K–S tests excluding the events showing an EE. We find that the associated probabilities increase, suggesting that the two classes of SGRBs do not show significant differences in their prompt emission properties (see Table 3, lower part).

### Table 4. BAT $T_{90}$ (in the 15–350 keV energy band), fluence and 1-s peak photon flux (from the time-averaged spectrum in the 15–150 keV energy band) for 44 SGRBs that were promptly observed by the Swift XRT up to 2011 January. The left-hand column represents SGRBs from Samples I and II, while the right-hand column represents all other SGRBs. EE indicates SGRBs with an extended emission. The errors at 90 per cent confidence level are given for fluence and 1-s peak photon flux. The table excludes EE. We find that the associated probabilities increase, suggesting that the two classes of SGRBs do not show significant differences in their prompt emission properties (see Table 3, lower part).

| GRB   | $T_{90}$ (s) | Fluence (10$^{-7}$ erg cm$^{-2}$) | 1-s peak photon flux (ph cm$^{-2}$ sec$^{-1}$) | GRB   | $T_{90}$ (s) | Fluence (10$^{-7}$ erg cm$^{-2}$) | 1-s peak photon flux (ph cm$^{-2}$ sec$^{-1}$) |
|-------|-------------|-------------------------------|---------------------------------------------|-------|-------------|-------------------------------|---------------------------------------------|
| 050724EE | 3.0 | 9.98 ± 1.20 | 3.26 ± 0.30 | 050509B | 0.048 | 0.09 ± 0.02 | 0.28 ± 0.10 |
| 051221A | 1.4 | 11.50 ± 0.35 | 12.00 ± 0.39 | 050813 | 0.6 | 0.44 ± 0.11 | 0.94 ± 0.23 |
| 051227EE | 8.0 | 6.99 ± 1.08 | 0.95 ± 0.12 | 050906 | 0.128 | 0.06 ± 0.02 | 0.22 ± 0.11 |
| 060313 | 0.7 | 11.30 ± 0.45 | 12.10 ± 0.45 | 05025 | 0.068 | 0.36 ± 0.00 | 0.10 ± 0.19 |
| 060801 | 0.5 | 0.80 ± 0.10 | 1.27 ± 0.16 | 051105A | 0.028 | 0.22 ± 0.04 | 0.32 ± 0.12 |
| 061005EE | 13.0 | 14.20 ± 1.42 | 5.24 ± 0.21 | 051210 | 1.3 | 0.85 ± 0.14 | 0.75 ± 0.12 |
| 070714B | 64.0 | 7.20 ± 0.90 | 2.70 ± 0.20 | 060502B | 0.09 | 0.40 ± 0.05 | 0.62 ± 0.12 |
| 070724AA | 0.4 | 0.30 ± 0.07 | 1.00 ± 0.20 | 061201 | 0.8 | 3.34 ± 0.27 | 3.86 ± 0.31 |
| 071227EE | 1.8 | 2.20 ± 0.30 | 1.60 ± 0.20 | 061217 | 0.3 | 0.42 ± 0.07 | 1.49 ± 0.24 |
| 080503EE | 17.0 | 20.00 ± 1.00 | 0.90 ± 0.10 | 070209 | 0.1 | 0.22 ± 0.05 | 0.38 ± 0.13 |
| 080702A | 0.5 | 0.36 ± 0.10 | 0.70 ± 0.20 | 070729 | 0.9 | 1.00 ± 0.20 | 1.20 ± 0.20 |
| 080905A | 1.0 | 1.40 ± 0.20 | 1.30 ± 0.20 | 070809 | 1.3 | 1.00 ± 0.10 | 1.20 ± 0.20 |
| 080919 | 0.6 | 0.72 ± 0.11 | 1.20 ± 0.20 | 070810B | 0.08 | 0.12 ± 0.03 | 1.80 ± 0.40 |
| 081226A | 0.4 | 0.99 ± 0.18 | 2.40 ± 0.40 | 080123EE | 115.0 | 5.70 ± 1.70 | 1.80 ± 0.40 |
| 090510 | 0.3 | 3.40 ± 0.40 | 9.70 ± 1.10 | 081024A | 1.8 | 1.20 ± 0.20 | 1.10 ± 0.10 |
| 090515 | 0.036 | 0.20 ± 0.03 | 5.70 ± 0.90 | 090305A | 0.4 | 0.75 ± 0.13 | 1.90 ± 0.40 |
| 090607 | 2.3 | 1.10 ± 0.20 | 0.70 ± 0.10 | 090621B | 0.14 | 0.70 ± 0.10 | 3.90 ± 0.50 |
| 100117A | 0.3 | 0.93 ± 0.13 | 2.90 ± 0.40 | 091109B | 0.27 | 1.90 ± 0.20 | 5.40 ± 0.40 |
| 100702A | 0.16 | 1.20 ± 0.10 | 2.00 ± 0.20 | 100206A | 0.12 | 1.40 ± 0.20 | 1.40 ± 0.20 |
| 100816AEE | 2.9 | 20.00 ± 1.00 | 10.90 ± 0.40 | 100213A | 2.4 | 2.70 ± 0.30 | 2.10 ± 0.20 |
| 101219A | 0.6 | 4.60 ± 0.30 | 4.10 ± 0.20 | 100625A | 0.33 | 2.30 ± 0.20 | 2.60 ± 0.20 |
|       |       |       |       | 100628A | 0.036 | 0.25 ± 0.05 | 0.50 ± 0.10 |
|       |       |       |       | 101224A | 0.2 | 0.58 ± 0.11 | 0.70 ± 0.20 |
shows that there is no clear anticorrelation between \( T_{90} \) and the host galaxy offset. Similar conclusions were also presented by Fong et al. (2010).

Extending this analysis, we checked if there is any correlation between \( T_{90} \) and the normalized host galaxy offset (see Fig. 3, bottom panel). In this case the data look somewhat less scattered. Calculating the Spearman rank correlation coefficient (without GRB 100117A), we obtain \( \rho_{\text{norm. offsets}} = -0.57 \pm 0.20 \) (\( p = 0.15 \)). For normalized host galaxy offsets, there is a hint of anticorrelation with \( T_{90} \).

Physical explanation for such correlation is not entirely known at present. Troja et al. (2008) suggested that the anticorrelation between \( T_{90} \) and the host galaxy offset may be due to different progenitors of SGRBs, arguing that SGRBs without an EE occur via NS–NS mergers. These have larger offsets from their host galaxy centre, while SGRBs with an EE occur via NS–BH mergers. Opposite to that, Church et al. (2011) argued that both BH–NS and NS–NS mergers have similar offset distributions, and Perna & Belczynski (2002) argued that different groups of NS–NS mergers exist, with a significant fraction of them merging well within their host galaxies. Norris, Gehrels & Scargle (2010) proposed that an EE, which is observed in \(~25\) per cent of SGRBs discovered by the \textit{Swift} satellite, is a part of the prompt emission, probably not directly caused by the properties of the surrounding environment. Their explanation for SGRBs’ dichotomy concerning an EE might be due to different progenitors: a compact binary merger (e.g. mass, angular momentum, etc.), while the progenitor type is only one. Alternatively, the temporally long-lasting soft tail observed in SGRBs could be originated by the afterglow emission and related to the density of the circumburst medium (Bernardini et al. 2007; Caiato et al. 2009, 2010; de Barros et al. 2011).

### 3.5 SL/LL X-ray afterglow

Sakamoto & Gehrels (2009) found that there exist two distinct classes of SGRBs based on the duration of the X-ray afterglow, namely SL, for which the X-ray afterglow flux at 10 s after the trigger is less than \( 10^{-13} \) erg cm\(^{-2}\) s\(^{-1}\), and LL, for which the X-ray afterglow flux is more than \( 10^{-13} \) erg cm\(^{-2}\) s\(^{-1}\). Based on the sample therein, Sakamoto & Gehrels (2009) concluded that SL SGRBs show no EE, no OA and a large host galaxy offset. We checked if this classification holds for SGRBs in our samples. Among them, there is GRB 100117A (Sample I), which based on the X-ray light curve and according to the definition of Sakamoto & Gehrels (2009) is SL, but it has an OA detected and a very small host galaxy offset. Besides that, in Sample II there are GRB 090515 (Rowlinson et al. 2010b), which is SL and shows no EE, but has an OA detected, and GRB 080503 (Perley et al. 2009), which is SL, but shows an EE and has an OA detected. Another possible candidate could be GRB 080905A, which has an OA detected, but we cannot confirm if it is SL due to the lack of the X-ray flux information around 10 s after the trigger, although its light curve looks very similar to the light curves of other SL SGRBs. We therefore conclude that there are SL SGRBs (GRB 080503, GRB 090515 and GRB 100117A), which have an OA detected and some also have an EE. According to these findings, the X-ray afterglow duration does not seem to be a unique indicator of a specific progenitor and/or an environment for SGRBs.

### 4 CONCLUSION

We presented here a systematic study of the environment of the SGRBs performed through the measure of their intrinsic X-ray absorbing column densities. Our results show that there are possibly two distinct populations of SGRBs. Half of them (Sample I with robust redshifts and Sample II without robust redshifts) show relatively bright X-ray afterglows and occur in dense environments, with X-ray column densities comparable to the one measured for the LGRBs in the same redshift range. Another half of them have very faint or no X-ray afterglow at all. The properties in the gamma regime of these two classes of SGRBs do not differ significantly, possibly suggesting that the observed difference in their X-ray afterglow brightness is not due to the burst energetics and might be a consequence of the environment where they explode.

We found no correlation between the intrinsic X-ray absorption and the host galaxy offset or normalized host galaxy offset. This is perhaps not expected for normalized host galaxy offsets; however, the results could be affected by the large uncertainties on the values of \( N_{\text{H}}(z) \) or by the fact that we are dealing with the projected offsets, which do not give us absolute position of a GRB inside its host galaxy along the line of sight.

We checked if SGRBs with an EE lie closer to the centre of their host galaxies. We found that there is no significant anticorrelation between the duration (\( T_{90} \)) and the host galaxy offset, but that there is a hint of anticorrelation when using the normalized host galaxy offsets instead.

We also tested if the SL SGRBs from our samples have no EE, no OA and a large host galaxy offset, as proposed by Sakamoto & Gehrels (2009). We found that this does not hold for all cases, since GRB 080503, GRB 090515 and GRB 100117A are SL, but have an OA detected. GRB 080503 also has an EE, while GRB 100117A has a very small host galaxy offset.

Finally, we want to stress that the sample of SGRBs with a robust redshift determination and host galaxy offset measured is quite
small up to this date (Sample I is about nine times smaller than the whole sample of LGRBs with known redshift from Campana et al. 2010, and almost twice as small as the subsample of LGRBs with $z < 0.923$), mainly due to their dim OAs. Thus, the results might be affected by the size of the sample. Future data will show if the conclusions, drawn in this paper, also hold on a larger sample.

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REFERENCES

Amati L., 2006, MNRAS, 372, 233
Amati L., Della Valle M., Frontera F., Malesani D., Guidorzi C., Montanari E., Pian E., 2007, A&A, 463, 913
Amati L., Guidorzi C., Frontera F., Malesani D., Pietsch W., 2008, MNRAS, 391, 577
Antonelli L. A. et al., 2009, A&A, 507, L45
Arnaud K. A., 1996, in Jacoby G., Barnes J., eds, ASP Conf. Ser. Vol. 101, Astronomical Data Analysis Software and Systems V. Astron. Soc. Pac., San Francisco, p. 17
Belczynski K., Kalogera V., 2001, ApJ, 550, L183
Belczynski K., Bulik T., Kalogera V., 2002, ApJ, 571, L147
Belczynski K., Perna R., Bulik T., Kalogera V., Ivanova N., Lamb D. Q., 2006, ApJ, 648, 1110
Berger E., 2009, ApJ, 690, 231
Berger E., 2011, New Astron. Rev., 55, 1
Berger E. et al., 2007, ApJ, 664, 1000
Bernardini M. G., Bianco C. L., Caio L., Dainotti M. G., Guida R., Ruffini R., 2007, A&A, 474, L13
Caio L., Bernardini M. G., Bianco C. L., Dainotti M. G., Guida R., Ruffini R., 2009, A&A, 498, 501
Caio L., Amati L., Bernardini M. G., Bianco C. L., de Barros G., Izzo L., Patricelli B., Ruffini R., 2010, A&A, 521, 80
Campana S., Thöne C. et al., 2008, ApJ, 676, 1151
Church R. P., Levan A. J., Davies M. B., Tanvir N., 2011, MNRAS, 413, 2004
Ciotti L., Bertin G., 1999, A&A, 352, 447
D’Avanzo P. et al., 2009, A&A, 498, 711
de Barros G., Amati L., Bernardini M. G., Bianco C. L., Caio L., Izzo L., Patricelli B., Ruffini R., 2011, A&A, 529, 130
Della Valle M. et al., 2006, Nat, 444, 1050
Eichler D., Livio M., Piran T., Schramm D. N., 1989, Nat, 340, 126
Evans P. A. et al., 2009, MNRAS, 397, 1177
Fong W., Berger E., Fox D. B., 2010, ApJ, 708, 9
Fong W. et al., 2011, ApJ, 730, 26
Fruchter A. S. et al., 2006, Nat, 441, 463
Fynbo J. P. U. et al., 2006, Nat, 444, 1047
Gal-Yam A. et al., 2006, Nat, 444, 1053
Gehrels N. et al., 2006, Nat, 444, 1044
Grindlay J., Portegies Zwart S., McMillan S., 2006, Nat, 2, 116
Hopman C., Guetta D., Waxman E., Portegies Z. S., 2006, ApJ, 643, L91
Kalberla P. M. W., Burton W. B., Hartmann D., Aarna E. M., Bajaja E., Morras R., Pöppel W. G. L., 2005, A&A, 440, 775
Kann D. A. et al., 2011, ApJ, 734, 96
Kouveliotou C., Meegan C. A., Fishman G. J., Bhat N. P., Briggs M. S., Koshut T. M., Paciesas W. S., Pendleton G. N., 1993, ApJ, 413, L101
Levesque E. et al., 2009, GCN Circ. 9264
Mangano V., 2007, A&A, 470, 105
Margutti R. et al., 2012, MNRAS, preprint (arXiv:1203.1059)
McBreen S. et al., 2008, ApJ, 677, L85
McBreen S. et al., 2010, A&A, 516, 71
Nakar E., 2007, Phys. Rep., 442, 166
Narayan R., Paczynski B., Piran T., 1992, ApJ, 395, L83
Norris J. P., Cline T. L., Desai U. D., Teegarden B. J., 1984, Nat, 308, 434
Norris J. P., Marani G. F., Bonnell J. T., 2000, ApJ, 534, 248
Norris J. P., Scargle J. D., Bonnell J. T., 2001, in Costa E., Frontera F., Hjorth J., eds, Gamma-Ray Bursts in the Afterglow Era. Springer-Verlag, Berlin, p. 40
Norris J. P., Gehrels N., Scargle J. D., 2010, ApJ, 717, 411
O’Leck E. O. et al., 2007, ApJ, 662, 1129
Perley D. A. et al., 2009, ApJ, 696, 1871
Perna R., Belczynski K., 2002, ApJ, 570, 252
Rowlinson A. et al., 2010a, MNRAS, 408, 383
Rowlinson A. et al., 2010b, MNRAS, 409, 531
Sakamoto T., Gehrels N., 2009, in Meegan C. A., Kouveliotou C., Gehrels N., eds, AIP Conf. Proc. Vol. 1133, Gamma-ray Bursts, 6th Huntsville Symp. Am. Inst. Phys., New York, p. 112
Salvaterra R., Cerutti A., Chincarini G., Colpi M., Guidorzi C., Romano P., 2008, MNRAS, 388, L6
Salvaterra R., Devecchi B., Colpi M., D’Avanzo P., 2010, MNRAS, 406, 1248
Savaglio S., Glazebrook K., Le Borgne D., 2009, ApJ, 691, 182
Tanvir N. R. et al., 2010, GCN Circ. 11123
Thöne C. et al., 2008, ApJ, 676, 1151
Thöne C. et al., 2011, MNRAS, 414, 479
Troja E., King A. R., O’Brien P. T., Lyons N., Casulano H., 2008, MNRAS, 385, L10
Ukwatta T. N., Gehrels N., Krimm H. A., Sakamoto T., Barthelmy S. D., Stamatikos M., 2009, GCN Circ. 9272
Ukwatta T. N., Barthelmy S. D., Gehrels N., Markwardt C. B., Norris J., Sakamoto T., 2010, GCN Circ. 10976
Wakker B. P., Lockman F. J., Brown J. M., 2011, ApJ, 728, 159
Watson D., 2011, A&A, 533, 16
Xu D. et al., 2009, ApJ, 696, 971
Zhang B., Zhang B.-B., Liang E.-W., Gehrels N., Burrows D. N., Mészáros P., 2007, ApJ, 655, L25

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