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The Low-Luminosity Afterglow Gamma-ray Bursts

Hüsne Dereli[1]★, Michel Boër[1], Bruce Gendre[1], Lorenzo Amati[2], Simone Dichiara[3]

[1] *ARTEMIS (CNRS, UMR 7250, OCA, UNS); Boulevard de l'Observatoire, BP 4229, F-06304 Nice, Cedex, France*

[2] *IASF-Bologna/INAF; Area della Ricerca di Bologna, Via Gobetti 101, 40129 - Bologna, Italy*

[3] *University of Ferrara; Via Savonarola 9, 44121 Ferrara, Italy*

Özet

The Low Luminosity Afterglow (LLA) gamma-ray bursts (GRBs) are characterized by their very intrinsically faint X-ray afterglows. They represent 12% of the long (of duration more than 2s) GRBs (lGRBs) with measured redshift. They are on average closer than the other lGRBs and their distribution is not affected by the gas and dust from our and host galaxies, and we detect jet breaks in some cases. We explore the environments of the LLA GRBs in the light of the closure relations, both in the X-ray and in the optical bands. We have also studied the host galaxy environment. We show that the prompt properties of LLA GRBs are somewhat different from that of other lGRBs, as shown by their position in the Amati relation. We have computed the volume density of LLA GRBs. Finally, using all these information we purpose an assumption that may be applicable about the origin of GRBs.

Anahtar Kelimeler: X-rays: bursts, Sıkı Nesneler

1 Introduction

Long Gamma-Ray Burst are thought to be the result of a cataclysmic collapse of a massive star (Woosley 1993). However, different sub-classes of long GRBs (under-luminous bursts (Watson 2004; Virgili 2009), ultra-long GRBs (Gendre 2013), dark bursts, X-ray flashes) were proposed in the literature. After a study of GRB afterglows observed by BeppoSAX, Chandra and XMM-Newton (Gendre 2005), in 2008, Gendre et al. (2008) showed the existence of a wide dispersion of the afterglow luminosity of long GRBs (from the brightest to the faintest ones). In this work, we have studied the faintest part of this distribution and we have chosen 31 GRBs hereafter designed by Low-Luminosity Afterglow (LLA) GRBs (Dereli 2014) by considering all long bursts with a measured redshift, observed before February 15^{th}, 2013 (corresponding to 254 bursts), by studying their X-ray afterglows after rescaling all the fluxes at z = 1 and applying a flux threshold of 10^{-13} erg s $^{-1}$ cm^{-2} at one day (which also corresponds to the lowest afterglow luminosity in D'Avanzo et al. (2012)) and by applying a template power-law with decay index 1.2 (corresponding to the typical value expected with p $\sim$ 2.3 where p is the power law index of the accelerated electrons in the cases of interstellar circumburst medium) in the flux-time plane.

LLA GRBs consist of 12% of lGRBs with a measured redshift. Their distribution is not affected by the gas and dust from the Milky Way and their host galaxies more than normal lGRBs (Dereli 2014). Most of the LLA GRBs are characterized by a fireball in the slow-cooling state expanding in the constant interstellar medium (ISM). The few outliers can be interpreted by a fireball expanding in a wind-like medium *e.g.* GRB 011121 or by the emission of a jet. We found jet break for GRB 060614 and GRB 120729A.

In this work, we used a standard flat ΛCDM model with $\Omega_{\rm m}$ = 0.3 and H$_0$ = 72 km s^{-1} Mpc^{-1}.

2 Redshift Distributions

There is a significant difference between the redshift distributions of LLA GRBs and normal lGRBs as seen in Figure 1a). This is also confirmed by the result of the Kolmogorov-Smirnov test show that the probability for two distributions to be based on the same population is 1.1×10^{-14}. LLA GRBs are on average closer than normal lGRBs. Obviously, the LLA GRB distribution is strongly biased against high redshifts. In order to have a fairer comparison, we restricted both distributions to $z < 1$, redshift for which we assumed that all LLA GRBs would be detected. Then we applied the Kolmogorov-Smirnov test. It shows that the probability for two distributions to be based on the same population is 9.4×10^{-4}. The lack of observations of intrinsically faint events at large distances can be explained by selection effects, however, there is no clue for the lack of intrinsically bright events in the local Universe.

3 Amati correlation: prompt properties of LLA GRBs

We also investigated the prompt properties of LLA GRBs. As seen in Figure 1b), all outliers to the Amati relation (Amati 2006) are in this sample. It is also found that the E$_{\rm p,i}$ values cluster broadly within the 40-200 keV range which can be a bias effect introduced by instrument. However, the situation is different with E$_{\rm iso}$. There is a clear shift in the E$_{\rm iso}$ axis with respect to most normal lGRBs. We conclude that LLA GRBs are less energetic during their prompt phase compared to normal lGRBs. Because of the correlation between L$_{\rm prompt}$ and L$_{\rm afterglow}$ (D'Avanzo et al. 2012), this is not surprising.

4 Host properties of LLA GRBs

The differences between the host galaxies of LLA GRBs and those of normal lGRBs are very small.

4.1 Mass and Metallicity

The mean value of the host masses is $10^{9.5}$ $\rm M_\odot$ for normal lGRBs, while it is slightly smaller for LLA GRBs, the mean value being $10^{9.1}$ $\rm M_\odot$. When we compared the host galaxies of the three samples (LLA GRBs, normal lGRBs and SDSS) at

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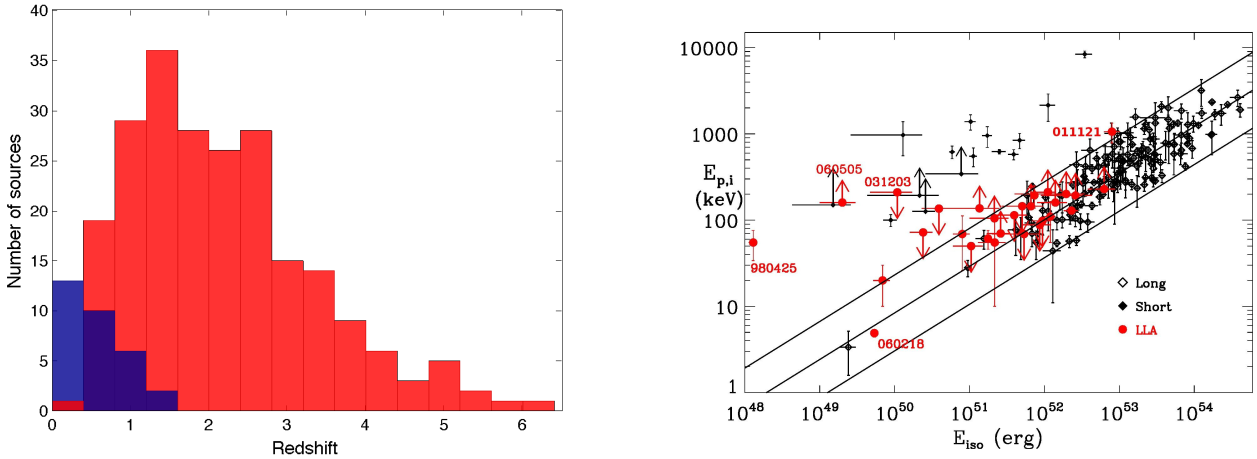
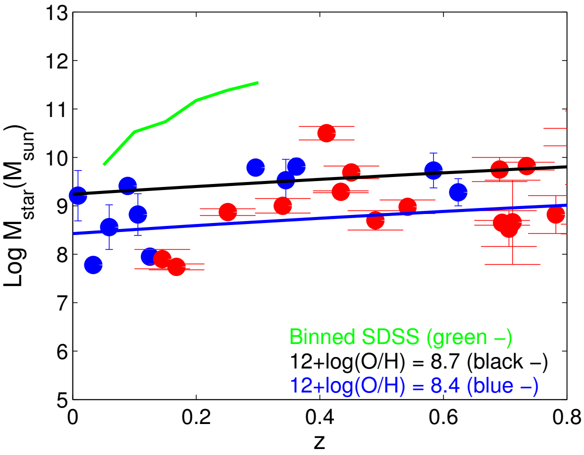
★ husnedereli@gmail.com



Şekil 1. a) Redshift distribution of LLA GRBs (blue) compared to that of normal lGRBs (red). b) Location in the $E_{p,i}$ - E_{iso} plane of LLA GRBs compared to both short and normal lGRBs.



Şekil 2. Mass-redshift distributions of LLA GRBs (blue filled circles) and lGRBs (red filled circles) host galaxies. The solid lines represent the mean value of the metallicity $12 + \log{(\mathrm{O/H})_{\mathrm{KK04}}} = 8.7$ (black) of SDSS galaxies (Savaglio 2005) and the mean value of the metallicity $12 + \log{(\mathrm{O/H})_{\mathrm{KK04}}} = 8.4$ (blue) of LLA GRB hosts. The green solid line represents the average binned mass of SDSS galaxies (Wang 2014).

a given matallicity, we found that host galaxies of GRBs have larger masses than those in the SDSS survey at a constant metallicity level, and that the normal lGRB host masses are slightly larger than the LLA GRB host masses at a constant metallicity level. This is seen in Figure 2.

4.2 Metallicity and Brightness

The comparison between the host galaxy properties of LLA GRBs and those of normal lGRBs is difficult since few magnitude values of the host galaxies were obtained. However, we found interesting that host galaxies of GRBs associated to type Ic SN have lower metallicity than that of GRBs without SN. In addition, the metallicity of the host of GRB 011121 associated to a type IIn SN, is also above the threshold (Modjaz 2008a) see Figure 3a).

Çizelge 1. The observed (considering V_{max}, S_{cov}, T and η_z) and intrinsic (also considering $B(\theta)$) total rate density are computed by using the parameters of the 25 LLA GRBs observed by *Swift*.

$R_{LLA\ GRB,\ obs}$ Gpc^{-3} yr^{-1}	$R_{LLA\ GRB,\ int}$ Gpc^{-3} yr^{-1}
358,83	285316.04

4.3 Star Formation Rate and Metallicity

It is clearly seen in Figure 3b) that the SFR of GRB hosts is larger compared to that of SDSS galaxies (Wang 2014). Additionally, the mean values for the star formation rate are $2.94\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$ for LLA GRBs and $6.29\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$ for normal lGRBs. The reason for this difference is that since less stars are formed as a whole, less very massive stars are formed as well, thus limiting the number of normal lGRBs. Thus, the possible progenitor of a LLA GRB would be less massive, and as a result the GRB less energetic.

5 Rate Density of LLA GRBs

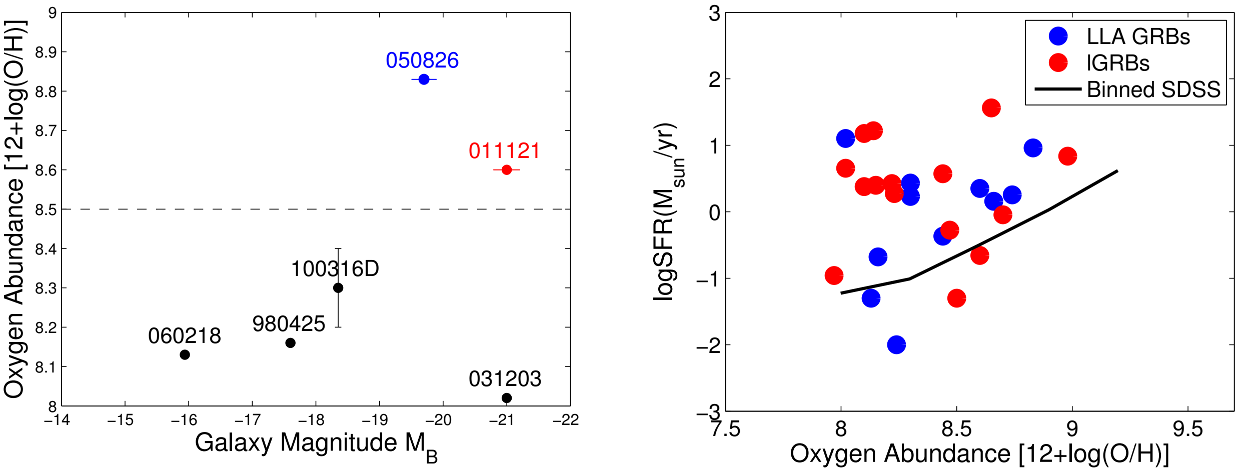
The rate density is calculated by considering only the LLA GRBs observed by the *Swift* satellite:

$$R_{GRB} = \frac{1}{V_{max}} \frac{1}{S_{cov}} \frac{1}{T} B(\theta) \frac{1}{\eta_z}, \tag{1}$$

where S_{cov} is the fractional sky coverage (which is 0.17 for *Swift*), T is the time during which the satellite was observing (6.4 years for LLA GRBs, which takes into account when *Swift* was not observing), V_{max} is the maximum volume (Coward 2012), $B(\theta) = [1 - \cos(\theta)]^{-1}$ and θ is the beaming angle. The efficiency of measuring the redshift η_z is 0.3 for lGRBs observed by the *Swift* satellite.

5.1 Comparison with long GRBs

We found out that the rate density of LLA GRBs is much higher than that of lGRBs (1 Gpc^{-3} yr^{-1} (Virgili 2009)), see Table 1. However, the rate density in our computation is dominated



Şekil 3. a) The distribution of metallicity-B magnitude of the host of LLA GRBs. The horizontal dashed line represents the cut-off limit of metallicity at $12 + \log(\mathrm{O/H})_{\mathrm{KD02}} = 8.5$ (Modjaz 2008a). GRBs associated to broad-line Ic SNe are presented by black points while GRB 011121 (associated to a type IIn SN) and GRB 050826 (no association to SN) are presented by red and blue points respectively. b) The SFR-metallicity distribution of LLA GRBs and lGRBs host galaxies.

by GRB 060218 and GRB 100316D (observed rate densities 212 Gpc^{-3} yr^{-1} and 145.6 Gpc^{-3} yr^{-1} respectively). This is because these two bursts are extremely close ($z < 0.1$) and their maximum fluxes are below the theoretical flux detection threshold. Interestingly, if we remove these two bursts from the computation, we found that the local rate density of LLA GRBs (1.23 Gpc^{-3} yr^{-1}) is compatible to that of normal lGRBs.

5.2 Comparison with short GRBs

Another comparison is performed between LLA GRBs and short bursts. This is important as the position of some LLA GRBs in the E_{p} - E_{iso} plane is compatible with the position of short GRBs. The total rate of short GRBs was estimated to be 8^{+5}_{-3} Gpc^{-3} yr^{-1} if the emission is not collimated in a jet, and 1100^{+700}_{-470} Gpc^{-3} yr^{-1} if it is collimated in a jet (Coward 2012). Thus, we can conclude that LLA GRBs (except GRB 060505) which are at the position of short GRBs in the E_{p}-E_{iso} plane cannot be considered as short bursts with a duration larger than 2 s, as their individual rate is too small compared to that of short GRBs and in addition as many of the LLA GRBs have an observed association to SN. So, performing the computation for GRB 060505 only gives a observed rate of 0.91 Gpc^{-3} yr^{-1}, comparable to the average rate (1 Gpc^{-3} yr^{-1}) of individual short bursts and this GRB has no known association to a SN.

6 Conclusions

LLA GRBs are on average closer and less energetic than normal lGRBs. In addition, they have larger rate density than that of normal lGRBs. However, the differences in the host galaxy properties are small, but it might be the result of a lack of statistics. All these elements put together might indicate a different progenitor for LLA GRBs. The higher rate density of LLA GRBs indicate that the initial mass function of star represent the low-mass, however, the companion SN type (I) need large masses star so we purpose that the ancestor should be in a binary system that can lose its hydrogen shell.

Acknowledgments

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