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Gamma-Ray Bursts' redshift distribution's dependence on their duration

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Abstract. Gamma-ray bursts (GRBs) are distant, extremely energetic, short (about 0.1-1000 sec) cosmic transients, which could sample the whole observable Universe. Two of the Gamma-Ray Bursts' important properties are the duration and the distance of the burst. We analyzed these two important quantities of the phenomena. We mapped their two-dimensional distribution and explored some suspicious areas. As it is well known the short GRBs are closer than the others, hence we search for parts in the Universe where the GRBs duration differs from the others. We also analyze whether there are any areas where the redshifts are differing.

Key words: data analysis – gamma-ray bursts

1. Introduction

According to Mészáros (2006), gamma-ray bursts (GRBs) are the most energetic explosions in the distant Universe. The most massive stars collapsing (collapsar model) (MacFadyen & Woosley, 1999; Zhang & Mészáros, 2002) and compact stars combining to become black holes or neutron stars are the two main models that potentially account for GRB events (Eichler et al., 1989). The second model had been validated by the finding of GW170814/GRB170814A (Abbott et al., 2017; Goldstein et al., 2017; Horváth et al., 2018; Bagoly et al., 2016, 2017).

Compared to star merging events, collapsing events are often longer and softer. Horváth (1998) based its identification of a third group on the duration–hardness plane (Horváth et al., 2004, 2006; Řípa & Mészáros, 2016; Horváth et al., 2018). Although the physical makeup of this intermediate group was not completely understood, it appears that the X-ray flash events may be related to the intermediate GRBs (Horváth et al., 2010; Pinter et al., 2017; Bi et al., 2018) and Balazs et al. (1998) showed that the sky distribution of GRBs not isotropic, since then, the topic has raised many questions and has therefore been actively researched in various databases (e.g. observations with BATSE: Vavrek et al. (2008); Balázs et al. (1999); Hakkila et al. (2018), with Fermi: Tóth et al. (2019); Horváth et al. (2019), and with Swift & Fermi data: Pérez-Ramírez et al. (2010); Hakkila et al. (2018); Bagoly et al. (2022)

As a result, the Giant GRB Ring (Balázs et al., 2015, 2018) and the Hercules-Corona Borealis Great Wall (Horváth et al., 2014, 2015; Horvath et al., 2020), the two greatest structures in the Universe, were found. The relationship between the location of the GRBs and their duration became immediately apparent following the first redshift measurement: the short GRBs are positioned closer than the lengthy GRBs. But because GRBs happen over such a long period of time, it is possible that some of their characteristics vary with distance (Bagoly et al., 2003; Suleiman et al., 2022; Kovács et al., 2019; Hatsukade et al., 2019; Toth et al., 2019).

One of the largest structures yet discovered, the ring of GRBs has a diameter of around 1.72 Gpc (5.6 billion light years) and is located at a distance of about 2.8 Gpc (9.1 billion light years) from Earth with a redshift of between 0.78 and 0.86. The ring, which is made up of nine GRBs, may be connected to a cosmic structure. Given recognized theoretical models, such a concentration thus seems incredibly implausible. There are theories that mention the presence of a massive supergalactic structure (Eingorn et al., 2023a,b). With a mean size of almost 5.6 billion light years, this would be an incredibly large structure of the universe. Because of its connection to star formation, such a supercluster can explain the GRBs' significant overdensity. It would be one of the biggest structures in the observable world if such a structure actually exist (Balázs et al., 2015, 2018).

2. Data selection & methods

Currently, nearly five hundred redshifts have been observed for GRBs. The Caltech GRBOX web-page contains most of them, therefore, in this analysis we use their data set (`https://sites.astro.caltech.edu/grbox/grbox.php`) On Fig. 1 we show the redshift vs. duration distribution of these 474 GRBOX GRBs.

To study whether the redshift distribution depends on the duration (T90) parameter, one can use several statistical tests. Here, we ordered the GRBs by duration and chose n consecutive ones. Since there are few short bursts with redshift bigger than one, we omitted the 53 GRBs which had $T_{90} \leq 5s$, and we analyzed only the remaining 421 GRBs. This group's redshift distribution was compared with the complementary $421 - n$ GRBs' redshift distribution using a Kolmogorov-Smirnov test (KS). We compared the redshift distributions starting the group at the k-th position. We carried out this process for different group sizes from $n = 8$ to $n = 99$. As an example, Fig. 2 shows the KS p value's (in logarithmic scale) dependence of k for $n = 18, 40$ and 63, respectively. Note that the short part was cut from the figures, since p is extremely low in the short

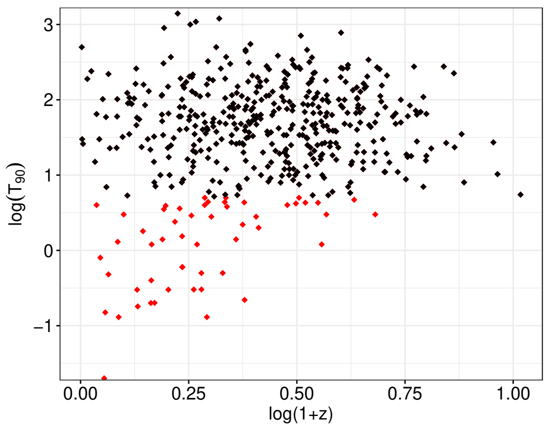

Figure 1. Redshift vs. duration (T90) distribution of the 421 non-short GRBs marked with black, and the omitted 53 GRBs with red.

duration area, which also means high significance. The green (0.0455) and blue (0.0027) lines show 2 and 3 sigma significance, respectively.

One can make a similar analysis by swapping the variables: order the GRBs by redshift, select a redshift interval, then compare the duration distribution of this subsample with the duration distribution of the complementary sample. We omitted the 53 GRBs which had $T_{90} \leq 5s$, too. Here we ordered the GRBs by redshift and chose the closest, consecutive n GRBs and compared the n closest GRBs' duration distribution with the $421-n$ GRBs' duration distribution, performing the Kolmogorov-Smirnov test (KS). We repeated this process starting from the k-th GRB and repeated the process with a block size of n running from 8 to 99.

3. Results

Fig. 3 shows the two-parameter (n, duration) KS p value. The p value reaches 0.0027 in two areas, the $16s < T_{90} < 20s$, $12 < n < 21$ and $49 < T_{90} < 61$, $23 < n < 36$. In these two areas the GRBs' T90 distribution differs significantly (more than 3σ) from the rest.

Fig. 4 shows the two-parameter (n, redshift) p value. The p value reaches 0.0027 in two areas, the $1.49 < z < 1.61$, $19 < n < 38$ and $2.91 < z < 3.075$, $11 < n < 19$ (Horvath et al., 2022). In these two areas the GRBs' redshift distribution differs significantly (more than 3σ) from the rest of the GRBs'.

We must emphasize that the KS test requires independent and identically distributed (IID) random variables, but the above method does not fulfil this

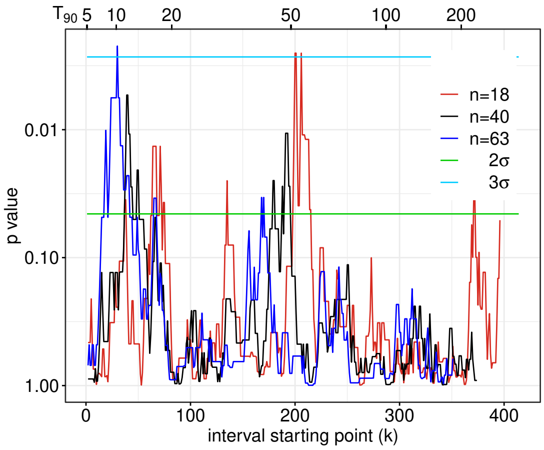

Figure 2. The logarithm of KS test p value as a function of the starting number of the n GRBs. Green (light blue) line marks the 2 (3) sigma significance level.

criteria since the n consecutive values are overlapping with each other until the difference between starting points is greater than n.

Please note, that we do not claim that there is any physical difference between the regions found in this study and the rest of the GRBs. We would like to point out that these areas are remarkable, and worth studying in more details in the future.

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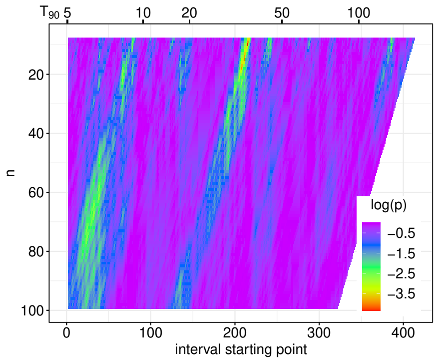

Figure 3. The two-parameter (n, duration) KS test p value surface plot using the 421 non-short GRBs. The 3 σ significance level is the color associated with $\log_{10}(p) \approx -2.57$.

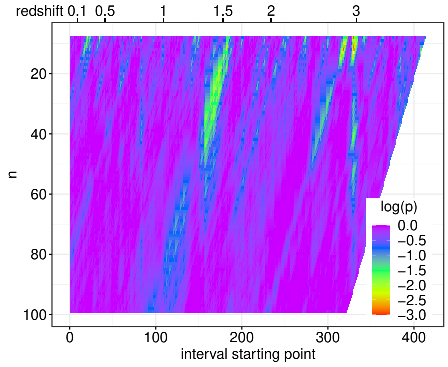

Figure 4. The two-parameter (n, redshift) KS test p value surface plot using the 421 non-short GRBs. The 3 σ significance level is the color associated with $\log_{10}(p) \approx -2.57$.

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