Different satellites - different GRB redshift distributions?

Z. Bagoly*, L. G. Balázs†, I. Horváth**, J. Kelemen‡, A. Mészáros‡, P. Veres* and G. Tusnády§

*Dept. of Physics of Complex Systems, Eötvös University, H-1117 Budapest, Pázmány P. s. 1/A, Hungary
†Konkoly Observatory, H-1525 Budapest, POB 67, Hungary
**Dept. of Physics, Bolyai Military University, H-1581 Budapest, POB 15, Hungary
‡Astronomical Institute of the Charles University, V Holešovičkách 2, CZ-180 00 Prague 8, Czech Republic
§Rényi Institute of Mathematics, Hungarian Academy of Sciences, H-1364 Budapest, POB 127, Hungary

Abstract. The measured redshifts of gamma-ray bursts (GRBs), which were first detected by the Swift satellite, seem to be bigger on average than the redshifts of GRBs detected by other satellites. We analyzed the redshift distribution of GRBs triggered and observed by different satellites (Swift[1], HETE2[2], BeppoSax, Ulysses). After considering the possible biases significant difference was found at the $p = 95.70\%$ level in the redshift distributions of GRBs measured by HETE and the Swift.

Keywords: γ-ray sources; gamma ray burst; statistical analysis

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INTRODUCTION

Greiner (http://www.mpe.mpg.de/~jcg) lists the observations concerning the afterglows of GRBs, and also selects and lists the confirmed redshifts. In [3] we analyzed Swift vs. all non-Swift spacecrafts redshift data between 01/01/2005-31/01/2006 : five statistical tests show $p \geq 99.40\%$ significance comparing the redshift distributions for the Swift and non-Swift samples. It suggested that the redshifts of the Swift sample are on average larger than that of the non-Swift sample.

Here we extend our work and use GRBs between 28/02/1997 and 03/05/2008 from Greiner’s survey. Since the Ulysses, ASM and XTR trio observed a total of 8 GRBs, therefore we aggregated them into one group (labeled Ulysses). The detailed statistics are the following:

| Spacecraft                  | GRB | GRB with $z$ | $z_{\text{min}}$ | $z_{\text{max}}$ |
|-----------------------------|-----|-------------|------------------|------------------|
| HETE                        | 79  | 20          | 0.1606           | 3.372            |
| SAX                         | 57  | 19          | 0.0085           | 3.9              |
| Swift                       | 315 | 103         | 0.0331           | 6.29             |
| Ulysses group (Ulysses + ASM + XTR) | 64  | 8           | 0.706            | 4.5              |

BIASES

To compare the $z$ distributions the Swift and non-Swift samples were compared using non-parametric rank based tests: the Kolmogorov-Smirnov test and the median test. These rank based tests have the clear advantage of being unaffected by any monotonous transformation in the $z$ values.

The Kolmogorov-Smirnov test compares the maximum difference in the cumulative distributions of the redshifts in the two samples. The median test compares the medians of the Swift and non-Swift samples as follows: he chosen $N_{\text{Swift}}$ objects randomly from the sample of the non-Swift events ($N_{\text{Swift}}$ denotes the number of GRBs in the Swift sample), and calculate the median. Repeat this e.g. 100000 times, and these Monte-Carlo simulations give the median distribution for $N_{\text{Swift}}$ random GRBs selected from the non-Swift group. Comparing this distribution with the real Swift median $z$ gives us the significance level for the null hypothesis that the two medians are equal.
FIGURE 1. The raw $n(<z)$ cumulative distribution of the different spacecrafts’ GRB observations.

FIGURE 2. The significance level changes with the length of the dataset

The significance of the Kolmogorov-Smirnov and the median test changes as new data arrive continuously from the spacecrafts. On Fig.2, the significances’ time dependences are shown as a function of the datasets’ end-date. Both values show gradual fall till 10/2006, however after the probabilities rise - while the length of the datasets grows! This kind time dependence indicates some fundamental change in the global observational strategy.

There are definite selections effects from satellite lifespan and sky coverage. E.g., the Swift’s X-ray afterglow observations revisit the earlier GRB directions and create hot spots in the GRB sky distributions on Fig.3. .

The optical follow-up observations’ sky coverage is strongly biased biased too, and it changes from spacecraft to spacecraft. It is due to the different technical limitations, telescope availability and the scientific community interest.

On Figs. 4-5, we show the non-isotropic redshift distribution of the SAX’s and Swift’s GRBs: both in the galactic and in the equatorial system there are strong selection effects. The galactic disk is clearly visible as a void around $-10 < b < 10$, and the clear cutoff in the redshift at low declinations shows that the majority of the optical observations were made on the northern hemisphere.
FIGURE 3. Swift’s GRB density function on the sky. The Voronoi-cell based density (white: low, black: high) is shown in the equatorial system. The dark hot spots with high observation probabilities are clearly visible.

FIGURE 4. SAX’s redshift-galactic latitude and redshift-declination distribution. The galactic disk is clearly visible as a void between $-10 < b < 10$. There are some signs of the north/south asymmetry, too.

FIGURE 5. Swift’s redshift-declination distribution and a full 3D sky distribution of the GRBs triggered by the Swift. The distance from the center is proportional with $z$, the convex hull of the north and south galactic hemisphere is also shown. One can observe the void around the galactic plane and the strong declination dependence, creating a north/south asymmetry.
FIGURE 6. Reconstructed \( n(<z) \) distribution of the different spacecrafts’ GRB.

RECONSTRUCTION

The observational biases demonstrated in the previous section can be accounted for - the reconstructions are similar to the magnitude limited quasar sample.

We used a reconstruction technique based on the Lynden-Bell’s C- method [4], [5] to generate weights from the untruncated part of the data and reconstruct the original (untruncated) density function.

Sort burst in ascending order by \( z \), and let \( \Omega_i \) be the solid angle where all bursts with \( z < z_i \) can be detected. In our case \( \Omega_{i+1} \subseteq \Omega_i \), which simplifies the analysis. We construct the real \( n(<z) \) cumulative density function in the following way: let \( N_i = \sum_{j \in \Omega_i} 1 \), i.e. there are \( N_i \) burst within the \( \Omega_i \) region. Here \( n(<z_i) \) is untruncated, hence \( n(<z_{i+1}) = n(<z_i)(N_i + 1)/N_i \). Starting the sequence with \( n(<z_1) = 1 \) we can reconstruct the cumulative density function.

For the \( \Omega_i \) sequences we considered both the \( b \) and declination cuts for each spacecrafts, determined from the real observational data. Fig.6. shows the reconstructed \( n(<z) \) cumulative distribution of the different spacecrafts’ GRB observations. Here the KS test gives \( p = 95.7\% \) for the HETE and Swift distribution.

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