Spatial Distribution of GRBs with Known Redshifts

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Abstract The conditional density method and the pairwise distances method to study gamma-ray bursts spatial distribution are used. The GRB sample is based on Swift program and includes 364 objects with measured redshifts and fluences. The main sample is divided into two cases. In both cases entire celestial sphere up to 8 Gpc is taken, but in the second case without Galactic belt. As a reference sample we use comparison of the real sample with the uniform distributions within the same geometry and the same number of points. Also we perform modeling of the luminosity function and Malmquist bias which allows to consider total sample without additional cuts such as volume limited subsamples. Our statistical analysis shows that the fractal dimension of the GRB sample, D, is about 2.6 on the range from 2 to 6 Gpc.

Keywords: gamma-ray bursts, large-scale structure of the Universe, fractal dimension.

1. Introduction

It is known that gamma-ray bursts (GRB) are the result of massive supernovae explosions and the neutron stars coalescence. Thus the GRB large scale distribution reflects large scale distribution of visible matter (galaxies). The nature of matter distribution on large scales is actual problem for cosmology and fundamental science ([1], [2]). The GRB extreme luminosity allows registering sources at large redshift (today up to 10 Gpc), which makes it possible the study of spatial distribution of galaxies on super large scales.

The correlation function method according to [3] gave correlation length of the Swift GRB space distribution $r_0 = 388\ h^{-1}$, index of correlation function $\gamma = 1.57 \pm 0.65$ (at 1σ level), and uniformity scale $r > 7700\ h^{-1}$ Mpc. The pairwise distances method was first applied in [4] to study of 201 GRB with known redshifts and angle coordinates, so the estimation of the fractal dimension was $D = 2.2 \div 2.5$. In [5] the giant ring of GRB with diameter 1720 Mpc was observed at $0.78 < z < 0.86$. The analysis of 352 Swift GRB in [6] gave at small scales the fractal dimension $D = 2.3 \pm 0.1$ in the ΛCDM frameworks, and $D = 2.5$ in other models.

However all these studies were performed without taking into account selection and distortion effects. In our work we study influence of the selection effects on the derived value of the fractal dimension. Also we get estimation of the fractal dimension for very large scales.

2. Data and Methods

We use the Swift GRB sample [7] which includes 364 objects with measured redshifts and fluences. The statistical analysis is based on determination of the fractal dimension of the GRB space distribution. Both the conditional density method ([1], [2], [8]) and pairwise distances method [9] are applied.

Since spatial distribution of 400 objects is poor to correct the determine of fractal dimension, it is necessary to modify the considered methods. First, ratio of distribution curves of non-uniform set to uniform set with the same number of points is should be regarded. This allows one to see the differences from the uniform distribution on all scales without considering the boundary effect. The slope of the graph is equal to D - 3. If a set is uniform then the graph will lie on the horizontal axis. Second, known sets is can be compared with real distribution. The three-dimensional Cantor's sets is selected for D = 2 and D = 2.5. In order to move from mathematical fractal to a model GRB catalog it is necessary take into account selection effects of the observations. The absorption in the galactic belt is approximated by cutting out points with a galactic latitude of more than 10 degrees in both hemispheres. Luminosity distribution of a model catalog together with the Swift catalog is shown on Fig1.

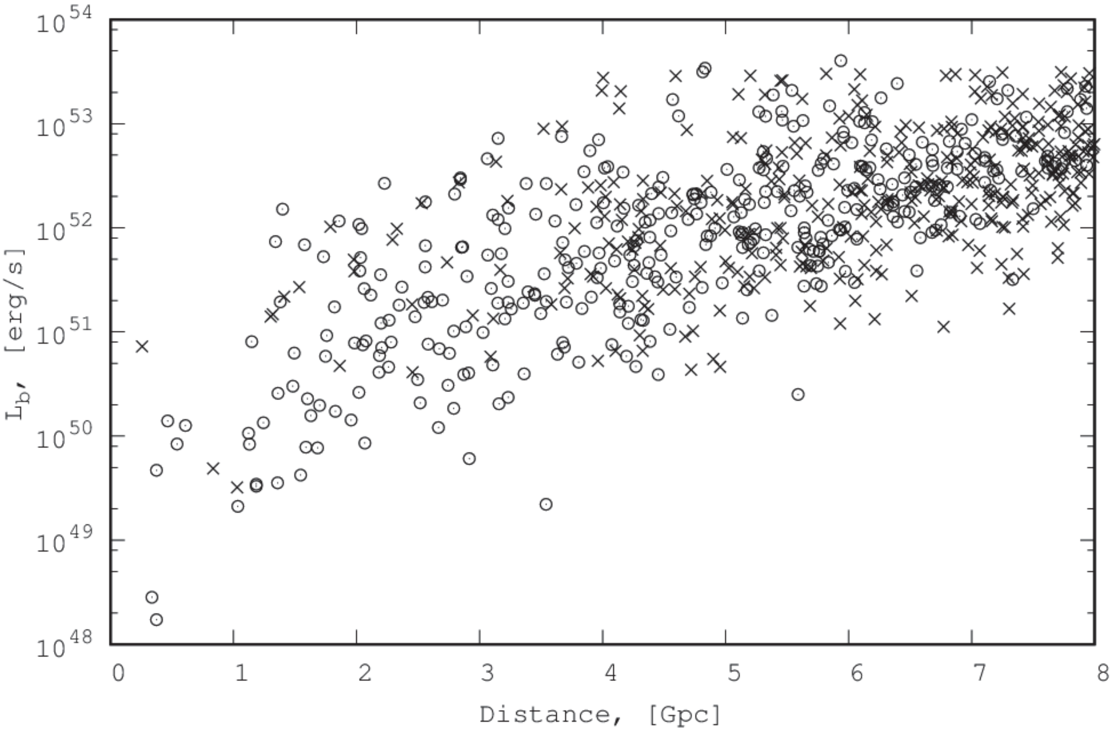

Fig1. *Luminosity distributions of the Swift GRB catalog (circles) and model catalog (crosses).*

The results of the methods are presented in Fig2 for the conditional density and in Fig3 for the pairwise distances. The model fractal catalogs are marked with the unfilled squares for D = 2 and circles for D = 2.5. The GRB Swift catalog is marked with the filled circles. An average distance between points is ~ 1 Gpc taken for the left border of the graphs. Since fractal dimension is given by graph slope in a log scale, it is necessary to consider the ratio of measured density to uniform distribution.

It can bee seen, that the behavior of the GRB curve looks like the fractal curve on the scale from 1.5 Gpc to 5 Gpc in both cases. At the same times, the GRB slope corresponding to D = 2.5 is clearly visible on the scale from 2.5 Gpc to 7 Gpc for the conditional density and from 1.5 to 7 Gpc for the pairwise distances. The directly approximated slope corresponds to D = 2.6, thus an accuracy of the fractal dimension estimation of this approach is ± 0.1.

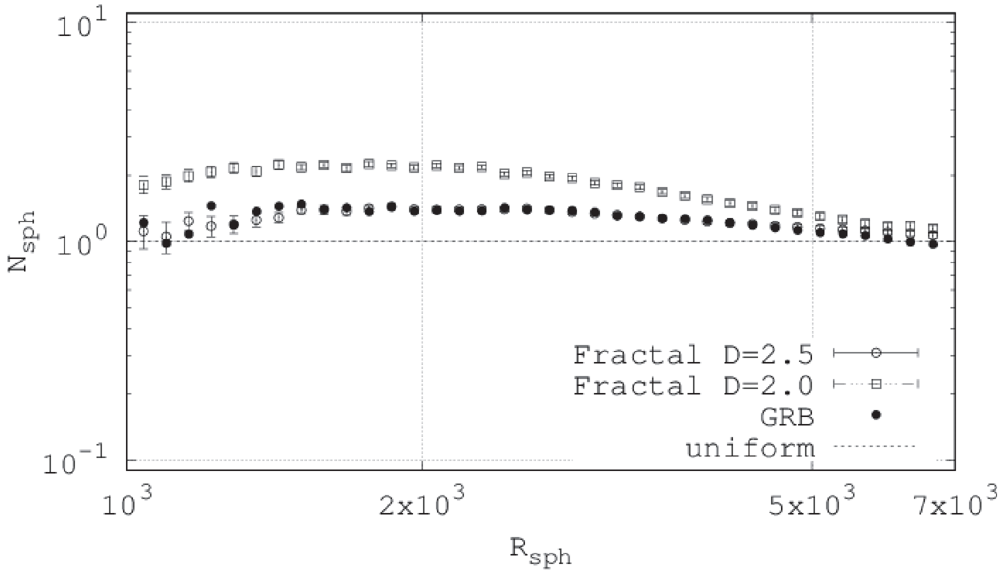

Fig2. *The conditional density distributions of the Swift GRB catalog and the model catalogs.*

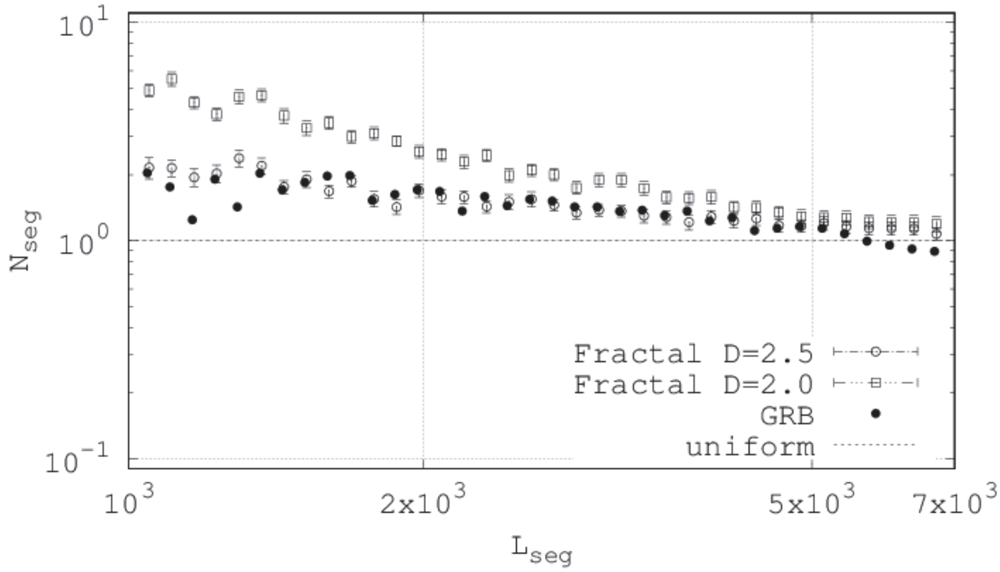

Fig3. *The pairwise distances distributions of the Swift GRB catalog and the model catalogs.*

3. Conclusion

At first time, the conditional density is successful calculated for GRB at scales up to 7 Gpc. The similarity of slopes for different methods allows to conclude that the fractal dimension of the spatial GRB distribution from Swift GRB catalog is 2.6 ± 0.1. The GRB graph slope is saved from 2.5 Gpc for the conditional density and from 1.5 Gpc for the pairwise distances up to 7 Gpc. This result is obtained due to the consideration of ratio fractal curves to uniform curves.

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