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SKY DISTRIBUTION OF GAMMA-RAY BURSTS: AN OBSERVATIONAL TEST OF THE FRIEDMANNIAN UNIVERSE MODELS

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Abstract. If the Universe is described by the Friedmannian model, then the objects located at redshifts larger than $z \simeq 0.1$ should be distributed isotropically on the sky. In order to fulfil the Cosmological Principle for these redshifts, the objects should be distributed homogeneously and isotropically. Various statistical isotropy tests are surveyed. Spherical tesselation, graph theoretical and multiscale methods are used to test the intrinsic isotropy of GRBs. The long gamma-ray bursts – being at these redshifts – show the isotropy; however, the conclusion is not decisive yet. Contrary to this, the short and intermediate bursts are not distributed isotropically; however, the redshifts are not known for these objects yet.

Key words: cosmology – gamma-rays: bursts

1. INTRODUCTION

The cosmological distance scale of gamma-ray bursts (GRBs) is compatible with their isotropic sky distribution. In previous studies we applied spherical harmonics (SH) (Balázs et al. 1999, Mészáros et al. 2000a), the so-called counts in cells method (CC) (Mészáros et al. 2000b) and the two-point correlation (TC) (Mészáros et al.

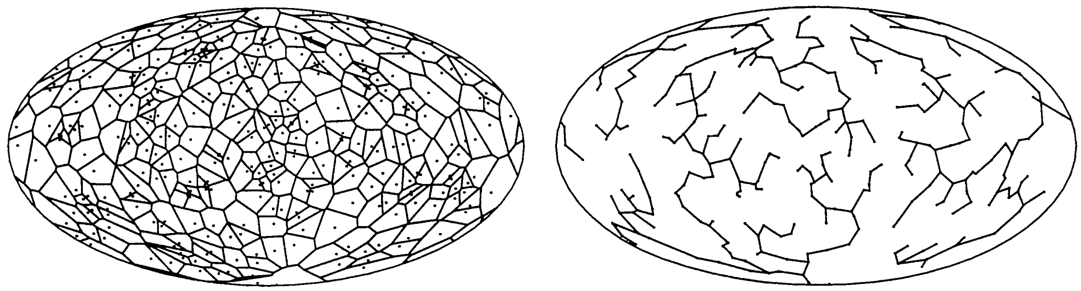

Fig. 1. Voronoi tesselation (a) and minimal spanning tree (b). Dots represent the locations of GRBs in the 2 s $\leq T_{90} \leq$ 10 s intermediate group.

2001) in order to test the isotropy of GRBs. In this paper we collect and compare all our results on the topic. Since accuracy and sensitivity against anisotropy are method-dependent, it is usually recommended to use different tools simultaneously in order to verify the null-hypothesis of intrinsic isotropy of the burst angular distribution.

2. SURVEY OF FURTHER METHODS

The spherical Voronoi cell corresponding to a given point in a point pattern on the sphere is defined as the region of sphere closer to the given point than to any other point of the sample (e.g., Stoyan & Stoyan 1994). The set of Voronoi cells for a point pattern, called the spherical Voronoi diagram, provides a partition of the sphere according to the structure of the pattern as shown in Figure 1a. The behavior of any tesselation method on the sphere is quite different than on the infinite plane. Since the 4π surface of the sphere is given, the Voronoi polygon areas will not be independent of each other. Clearly, the tails of the cell area frequency distribution are the most affected in the case of anisotropy. This feature makes a very efficient use of the spherical Voronoi tesselation (VT) to detect clustering over a wide range of spatial frequencies. Besides cell areas we examine the cell perimeter, roundness, inner angle distributions and their combinations.

For a given spherical point pattern, the minimal spanning tree (MST) is defined as the unique graph connecting all the points (Eppstein 2000), with no closed loops and having minimal length (see Figure 1b). For this reason, the total length of its edges form a minimal covering of the set. This graph contains $N(N-1)/2$ edges, where N is the number of nodes (the number of points in the set). We calculate the statistics of the MST edge length and angle (between two edges) frequency distributions. The dual graph of the Voronoi diagram is a triangulation of the sites. This graph is the so-called Delaunay triangulation, built up by a set of lines connecting points whose Voronoi diagrams share an edge. Furthermore, the MST of a point set forms a subgraph of the Delaunay triangulation, hence VT and MST are not completely independent structures. Their sensitivity on different signs of anisotropy (e.g., clustering or filamentary structures) is clearly different.

Multifractality is a generalization of the monofractal properties (e.g., Paladin & Vulpiani 1987) that arise naturally in case of self-similar point fields. A monofractal set is characterized by a single measure (usually the capacity dimension), however, it is possible that self-similarity is only local and different scaling laws are observed at different scales and locations. The term multifractal (MFR) on a point is applied when many fractal subsets with different scaling properties coexist simultaneously. If we denote a measure as μ, the Hölder exponent at x_i is $\mu_{x_i}(r) \propto r^{\alpha(x_i)}$.

$$f(\alpha) = d_F(\{x_i \in A \mid \alpha(x_i) = \alpha\}). \tag{1}$$

This singularity or MFR spectrum of point set A associates a fractal dimension d_F of any point x_i with $\alpha(x_i)$. The function $f(\alpha)$ is a single-peaked convex function with maximum $\max_x[f(\alpha)] = D$, where D is the monofractal dimension of the point set. In case of $D = 2$ (what is applicable for GRB groups) the MFR spectrum is not necessarily reduced into a single point but characterizes the entire structure of the point pattern and remains highly sensitive to anisotropy.

3. DETECTION OF ANISOTROPY

The above outlined methods were applied for subgroups of GRBs (short: $T_{90} < 2$ s, intermediate: 2 s $\leq T_{90} \leq 10$ s, long: $T_{90} > 2$ s) and for Monte-Carlo simulated random patterns. In the production of the 3×1000 random samples the BATSE non-uniform sky exposure function was taken into account. Confidence levels are derived from Kolmogorov-Smirnov tests where the observed distributions (or MFR spectra) are tested against the mean of the 1000 simulated distributions (spectra). A high confidence level means that we reject the null-hypothesis of intrinsic isotropy of GRBs angular distribution. The results of tests with the highest obtained confidence levels are collected in Table 1. The following conclusions can be made: (1)

the null-hypothesis of the randomness of long subgroups holds; (2) the randomness in the intermediate subclass is rejected at least on the >96.4% confidence level; (3) the short subgroup seems to be also anisotropic and the minimum >96.0% confidence level is reached. Applying a surface density estimator, Litvin et al. (2001) concluded on similar results (99.99% for the short and 99.89% for the intermediate group).

Table 1. Confidence levels of intrinsic anisotropy.

Group	SH	CC	TC	VT	MFR	MST
Short	–	–	99.2%	99.9%	96.0%	99.9%
Intermediate	97.0%	96.4%	99.8%	99.8%	98.2%	97.1%
Long	–	–	99.8%	–	–	97.0%

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