Spatial distribution of gamma-ray bursts (both in redshift and in the angular sky position)

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Abstract Gamma-ray bursts (GRBs) are at cosmological distances. Because there is no gap at the Galactic plane, they can well serve to test the fulfillment of the cosmological principle requiring a spatially homogeneous and isotropic distribution. In this contribution the author's and his collaborators' efforts are surveyed concerning the spatial distribution - both in redshift and in the angular distribution. Bold anisotropies are found in the dataset gained by the BATSE instrument of the Compton Gamma Ray Observatory.

Keywords: Gamma-Ray Burst, Spatial Distribution, Redshift

1. Introduction

The observable part of the universe is finite and has the size of $\sim (10 - 20)$ Gpc depending on the omega parameters. On the other hand, the redshifts of observed objects can be arbitrarily large. The relevant exact formulas for this behavior can be found, e.g., in Weinberg (1972) and Carroll et al. (1992). In this observable part the cosmological principle should be fulfilled, i.e. the Universe should be spatially homogeneous and isotropic on scales larger than the size of any structure, because in accordance with the cosmological principle "...in the large scale average the visible parts of our universe are isotropic and homogeneous" (Peebles 1993, page 15). But, on the other hand, the averaging should happen far below the $\sim(10 - 20)$ Gpc scales.

Trivially, any observational results from the high redshifts regions of the Universe are highly useful from the cosmological point of view. For smaller redshifts, say till $z \sim 1$, the Universe is hardly homogeneous and isotropic (see, e.g., Yadav et al. (2010) and Clowes et al. (2013)) - for larger redshifts there are also some hints about the possible departure from the isotropy (cf. Birch (1982)).

The gamma-ray bursts (GRBs) are partly at higher redshifts (for the survey of the topic see, e.g., Vedrenne & Atteia (2009)). In addition, they are not vanishing at the Galactic plane. Hence, they are ideal objects to test observationally the fulfillment of the cosmological principle.

In this contribution the statistical studies of the spatial distribution of gamma-ray bursts (GRBs) - done mainly by the author and his collegues - are briefly summarized.

2 Redshifts

Probably the first article about the redshifts of GRBs was presented by Usov & Chibisov

(1975). The article claims that, if GRBs are at cosmological distances, there should be a deviation from the $\log N(>F) \propto (-3/2) \log F$ relation expected for the Euclidean space (F is the so called peak-flux, and $N(>F)$ denotes the number of bursts having bigger peak-fluxes than F). In addition, from the character of this deviation the redshifts of objects can be deduced. In 1986, i.e. at the year when even the cosmological origin was in doubt, Paczyński (1986) has shown that GRBs should be at $z \simeq (1-2)$ (z denotes the redshift).

In 1995-98 the author and his colleagues confirmed the Paczyński's conclusion and have shown that GRBs can be till $z \simeq 20$ (Mészáros & Mészáros 1995, Mészáros & Mészáros 1996, Horváth et al. 1996). Note here that also in 1995-96 only indirect evidences existed for the cosmological origin, because the first direct measurement of a redshift appeared at 1997 by the BeppoSAX satellite (Costa et al. 1997).

In 2006 it was shown that mainly the long GRBs should follow the star-formation-rate (Mészáros et al. 2006).

A highly remarkable result was published in 2011 claiming that in average the fainter bursts can be at smaller distances (Mészáros et al. 2011).

3. Angular sky distribution

The angular sky distribution of the Galactic objects should show a concentration toward the Galactic plane in the angular sky distribution. On the other hand, the extragalactic objects should have no concentration toward the Galactic plane. From this expectation the first indirect observational proof for the cosmological origin of GRBs was given by Meegan et al. (1992). No concentration on the sky positions of GRBs toward the Galactic plane was observed. This indirect support of the cosmological origin was then provided by Tegmark et al. (1996). This study also did not find any concentration toward the Galactic plane and, in addition, did not find any deviations from the isotropic celestial distribution. It is essential to precise here there are two things here: No concentration toward the Galactic plane proves simply the extragalactic origin, but no deviation from the isotropic distribution in generals expected from the fulfillment of the cosmological principle. Both these expectations were declared in 1996 by Tegmark et al. (1996).

In 1998 Balázs et al. (1998) accepted the extragalactic origin of GRBs, and hence did not search for any concentration toward the Galactic plane. But in this study by statistical tests the isotropy of the sky distribution were provided in general. Today it is clear that this paper claimed first that the sky distribution of short BATSE's GRBs was not isotropic. This highly remarkable result was then verified by several other articles of the author and his collaborators (Balázs et al. 1999, Mészáros et al. 2000a, Vavrek et al. 2008). In addition, both the BATSE's intermediate and long subclasses were found to be distributed also anisotropically (see Mészáros et al. (2000b), Mészáros & Štoček (2003) and Vavrek et al. (2008) for more details and references).

In Figures 1-3 the angular distributions of the BATSE's three subgroups are shown.

After Vavrek et al. (2008) these statistical tests allowed to claim in 2009 the existence of the Gpc structures and thus the huge problems of the cosmological principle (Mészáros et al. 2009a, 2009b).

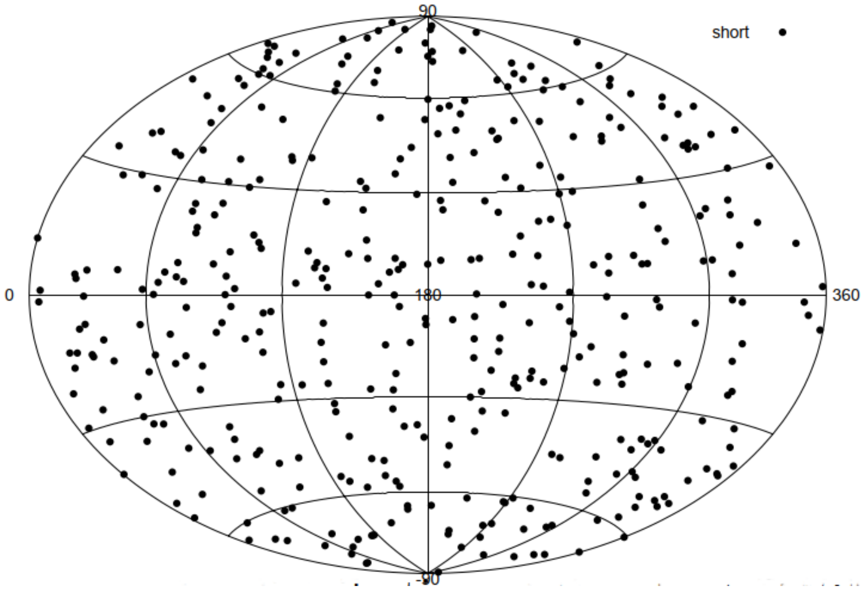

Fig1. *The angular sky distribution of the short BATSE's bursts in equatorial coordinates. Balázs et al. (1998) claim that the distribution is anisotropic.*

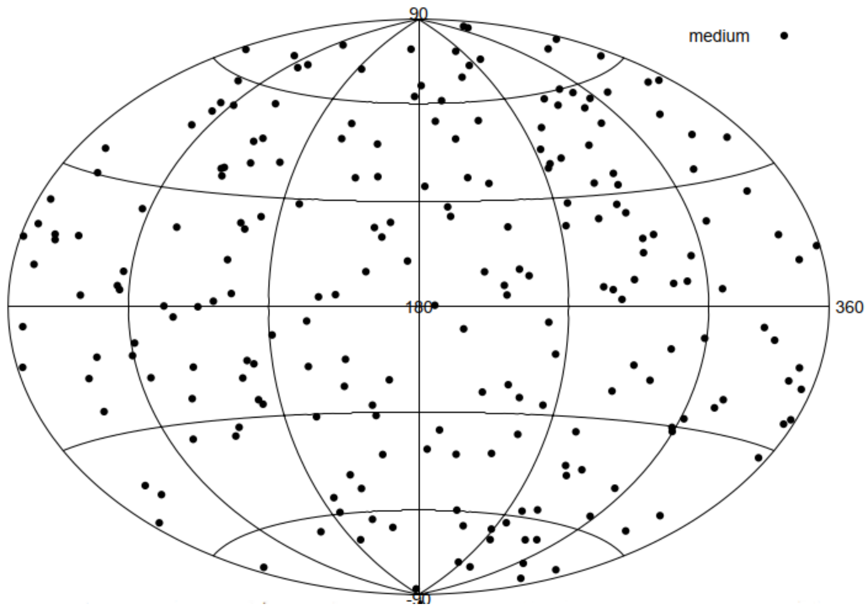

Fig2. *The angular sky distribution of the intermediate BATSE's bursts in equatorial coordinates. Mészáros A. et al. (2000) claim that the distribution is anisotropic.*

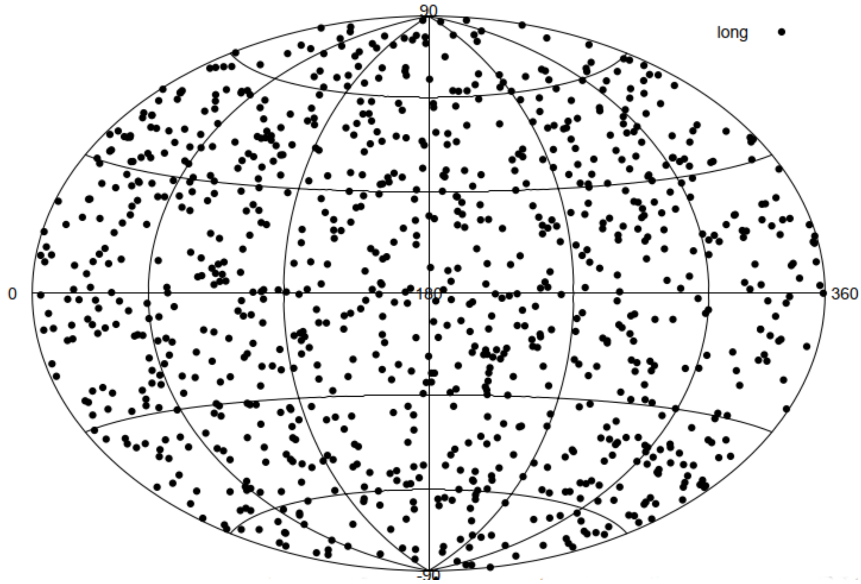

Fig3. *The angular sky distribution of the long BATSE's bursts in equatorial coordinates. Mészáros A. & Štoček (2003) claim that the distribution is anisotropic.*

4. Further studies

The studies, mentioned at the previous section were 2D studies and were based on the BATSE data. Direct 3D study of the BATSE data is not possible, because in the BATSE dataset only few GRBs have measured redshifts (Bagoly et al. 2003, Mészáros et al. 2011).

Recently two other groups obtained remarkable results from the 2D study of the dataset of the Fermi satellite.

At the whole Fermi dataset Tarnopolski (2017) found anisotropy for the short subclass of GRBs; for the long subclass the assumption of isotropy was not rejected by his tests. Řípa & Shafieloo (2017) - using the whole Fermi dataset - tested the isotropy of the observed properties of GRBs. This means that it was studied the possibility that at different directions GRBs had different properties such as their durations, fluences, and peak fluxes at various energy bands and different timescales. In other words, not the isotropy of the angular sky positions itself, but the isotropies of the observed properties themselves, were tested. Some noticeable anisotropic features were found, but a later study on a larger Fermi sample (Řípa & Shafieloo 2018) did not confirm any deviation from the isotropy of the observed properties. The same result was obtained for the BATSE and Swift datasets, respectively, too (Řípa & Shafieloo 2018).

For a small sample of GRBs, which have directly measured redshifts from the afterglows, the study of 3D structures became directly possible. But, only a small fraction of GRBs has directly measured redshifts (Perley 2017), and hence selection effects can play here an important role. Under these conditions huge spatial structures on the Gpc scales were found (Horváth et al. 2014, Horváth et al. 2015, Balázs et al. 2015, Sokolov et al. 2015, Verkhodanov et al. 2015, Bagoly et al. 2016a, Bagoly et al. 2016b), but Balázs et al. (2018) notes that “the large-scale spatial pattern of the GRB activity does not necessarily reflects the large-scale distribution of the cosmic matter”.

5. Conclusion

The results of the author’s, his collaborators’ and others’ efforts can be summarized as follows.

1. Existence of huge redshifts were claimed already in years 1995-96, when even the direct proof of the cosmological origin did not exist yet.

2. Both the 2D and 3D studies show that in the distribution of GRBs structures on the huge Gpc scales can well exist. All this challenges the cosmological principle.

References

[1] Bagoly, Z. et al. 2003, A&A, **398**, 919

[2] Bagoly, Z. et al. 2016a, Galaxies at High Redshift and Their Evolution Over Cosmic Time, IAU Symp. **319**, 2

[3] Bagoly, Z. et al. 2016b, Galaxies at High Redshift and Their Evolution Over Cosmic Time, IAU Symp. 319, 3

[4] Balázs, L.G., Mészáros, A., & Horváth, I. 1998, A&A, **339**, 1

[5] Balázs, L.G. et al. 1999, A&AS, **138**, 417

[6] Balázs, L.G. et al. 2015, MNRAS, **452**, 2236

[7] Balázs, L.G. et al. 2018, MNRAS, **473**, 3169

[8] Birch, P. 1982, Nature, **298**, 451

[9] Carroll, S.M., Press, W.H. & Turner, E.L. 1992, ARAA, **30**, 499

[10] Clowes, R.G. et al. 2013, MNRAS, **429**, 2910

[11] Costa, E. et al. 1997, Nature, **387**, 783

[12] Horváth, I., Mészáros, P. & Mészáros, A. 1996, ApJ, **470**, 56

[13] Horváth, I., Hakkila, J. & Bagoly, Z. 2014, A&A, **561**, L12

[14] Horváth, I. et al. 2015, A&A, **584**, A48

[15] Meegan, C.A. et al. 1992, Nature, **355**, 143

[16] Mészáros, A. & Mészáros, P. 1996, ApJ, **466**, 29

[17] Mészáros, P. & Mészáros, A. 1995, ApJ, **449**, 9

[18] Mészáros, A., Bagoly, Z. & Vavrek, R. 2000a, A&A, **354**, 1

[19] Mészáros, A. et al. 2000b, ApJ, **539**, 98

[20] Mészáros, A. & Štoček, J. 2003, A&A, **403**, 443

[21] Mészáros, A. et al. 2006, A&A, **455**, 785

[22] Mészáros A. et al. 2009a, Baltic Astronomy, **18**, 293

[23] Mészáros A. et al. 2009b, Sixth Huntsville GRB Symposium, AIP Conf. Proc., **1133**, 483

[24] Mészáros, A. et al. 2011, A&A, **529**, A55

[25] Paczyński, B. 1986, ApJL, **308**, L43

[26] Peebles, P.J.E. 1993, Principles of Physical Cosmology (Princeton University Press)

[27] Perley, D. 2018, http://www.astro.caltech.edu/grbox/grbox.php

[28] Řípa, J. & Shafieloo, A. 2017, ApJ, **851**, article id. 15,

[29] Řípa, J. & Shafieloo, A. 2018, arXiv:1809.03973

[30] Sokolov, I.V. et al. 2015, Quark Phase Transition in Compact Objects, SAO, Russia, 111

[31] Tarnopolski, M. 2017 MNRAS, **472**, 4819

[32] Tegmark, M. et al. (1996), ApJ, **468**, 214

[33] Usov, N.V. & Chibisov, G.V. 1975, Soviet Astronomy, **19**, 115

[34] Vavrek, R. et al. 2008, MNRAS, **391**, 1741

[35] Vedrenne, G. & Atteia, J.-L. 2009, Gamma-Ray Bursts: The brightest explosions in the Universe (Springer)

[36] Verkhodanov, O.V., Sokolov, V.V. & Khabibullina, M.L. 2015, Quark Phase Transition in Compact Objects, SAO RAS, Russia, 142

[37] Weinberg, S. 1972, Gravitation and Cosmology (J.Wiley, New York - London - Sydney - Toronto)

[38] Yadav, J.K., Bagla, J.S. & Khandai, N. 2010, MNRAS, **405**, 2009