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REVIEW ARTICLE

An Oppositeness in the Cosmology: Distribution of the Gamma-Ray Bursts and the Cosmological Principle

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The Cosmological Principle is "the assumption that the universe is spatially homogeneous and isotropic in the large-scale average" (Peebles P.J.E., Principles of Physical Cosmology, Princeton Univ. Press, 1993). In year 1998 the author, together with his two colleagues, has shown that the BATSE's short gamma-ray bursts are not distributed isotropically on the sky. This claim was followed by other papers confirming both the existence of anisotropies in the angular distribution of bursts and the existence of huge *Gpc* structures in the spatial distribution. These observational facts are in contradiction with the Cosmological Principle, because the large scale averaging hardly can be provided. The aim of this contribution is to survey these publications.

KEYWORDS:
cosmology: large-scale structure of Universe, gamma-ray burst: general

1 | COSMOLOGICAL PRINCIPLE FROM THE OBSERVATIONAL POINT OF VIEW

The Cosmological Principle requires that the Universe be spatially homogeneous and isotropic on scales larger than the size of any structure (Peebles (1993)). On the page 15 of this book it is said: "...in the large scale average the visible parts of our universe are isotropic and homogeneous".

The observable part of the Universe has the size of $\sim (10-20)\,Gpc$, if one uses the so called "proper-motion distance". The relevant formulas are given, e.g., by Weinberg (1972) and Carroll, Press, & Turner (1992). The exact value depends on the omega-factors and on the Hubble-constant. In any case, the observable part is finite, if the so-called "proper-motion distance" is used, which is always given by luminosity-distance$/(1+z)$, where z is the redshift.

Trivially, the averaging should happen far below the $\sim (10-20)\,Gpc$ scale. In other words, there should exist a transition scale not larger than, say, ~ 1 Gpc, and above this one no structures should exist. Yadav, Bagla, & Khandai (2010) means that this transition scale is $\simeq 260h^{-1}$ Mpc, where h is the Hubble-constant in unit 100 km/(sMpc). But, if there were observed structures of scales $\sim 1\,Gpc$, then the Cosmological Principle hardly can hold.

It is widely accepted that the Cosmological Principle holds. But, on the other hand, there are publications with observational supports for the structures with $\sim$ *Gpc* sizes. For example, Collins & Hawking (1973) and Birch (1982) speak about a possible global rotation in the observable part of the Universe. Other observations (Rudnick, Brown, & Williams (2007)) claim the existence of structure with size ~ 140 Mpc, but at redshift around 1. A recent publication about the spatial distribution of quasars (Clowes et al. (2013)) claims the existence of a structure with a scale > 1 Gpc.

The spatial distribution of the gamma-ray bursts (hereafter GRBs) allows to test this Principle. In any case, the GRBs should be distributed isotropically on the sky. For this test GRBs are especially useful, because they are seen in the gamma-band also in the Galactic plane, too, and thus there is no observational bias following from the absorption at the Galactical plane. In year 1996 it was declared that the isotropic angular distribution of BATSE's bursts was fulfilled (see Tegmark, Hartmann, Briggs, Hakkila, & Meegan (1996) and the references therein). For GRBs, when the redshifts are directly measured, not only the angular distribution can be tested, but also the three-dimensional spatial distribution.

2 | REDSHIFTS AND SUBSAMPLES OF GRBS: A BRIEF DESCRIPTION

The first article about the discovery of 16 GRBs was published in 1973 (Klebesadel, Strong, & Olson (1973)). In period 1973-1990 $\simeq (10-20)$ GRBs were detected annually. In years 1990-2000 the BATSE instrument on the Compton Gamma-Ray Observatory increased the number of detected GRBs and confirmed that there are two types of GRBs (the "short-/hard" and the "long/soft" separation). It was also confirmed indirectly that both types of GRBs are at cosmological distances (see Paczyński (1986), Meegan et al. (1992), Mészáros & Mészáros (1995), Mészáros & Mészáros (1996), Horváth, Mészáros, & Mészáros (1996), Goldstein et al. (2013) and the references therein). It was also claimed that the redshifts can be till $z \sim 20$ (Mészáros & Mészáros (1996)). The indirect proof of the cosmological origin followed from the statistical studies of the angular distribution of GRBs - they did not show any concentration toward the Galactical plane (Meegan et al. (1992), Tegmark et al. (1996)).

At year 1997 a long GRB was detected also at other photon energy bands, because the so-called "afterglow" was followed after the discovery of the BeppoSAX satellite (Costa et al. (1997)). After that, at the coming years, it was observationally confirmed that the long GRBs are connected to the supernovae (for details see, e.g., Woosley & Bloom (2006)). For the short ones only in 2013 came the observational support that they are given by the merging of two neutron stars (black holes) forming macronovae (Tanvir et al. (2013)). The simultaneous detection of the gravitational wave and macronova (also the term "kilonova" is used) from 17 August 2017 confirmed that the observed gravitational waves and the short GRBs should have common origin (von Kienlin et al. (2019)).

It has to be noted that there are several statistical studies claiming that - beyond the short and long ones - also other subgroups exists for GRBs (for details and other issues see, e.g., Levan et al. (2014), Řípa, Mészáros, Veres, & Park (2012), Řípa & Mészáros (2016) and the references therein). Summing up these efforts it can be said that there are several supports for the existence of astrophysically different subclasses of GRBs - but, on the other hand, no unambiguous proof exists for the existence of more than two types.

3 | ANISOTROPIES IN THE BATSE SAMPLE

The first indirect observational proof for the cosmological origin of GRBs was given by Meegan et al. (1992). There was no concentration in the sky positions of the observed BATSE's GRBs with respect to the Galactical plane. This indirect support of the cosmological origin was then collected and formulated by Tegmark et al. (1996). This study did not find any concentration toward the Galactical plane and did not find also any deviation from the isotropic celestial distribution.

Balázs, Mészáros, & Horváth (1998) accepted a priori the cosmological origin of GRBs, and hence they did not search for any concentration toward the Galactical plane. They studied generally by statistical tests the isotropy itself in the sky distribution. Hence, in essence, they tested the fulfilment of The Cosmological Principle, because - if fulfilled - the distribution must remain isotropic. The paper unambiguously claims first on a high significance level that the sky distribution of the short BATSE's GRBs is not isotropic. On Fig.1 this distribution is shown. It must be precised that the anisotropy is not given by the instrumental effects coming from the fact that the BATSE instrument did not observe uniformly at different declinations.

This proclaim about the short BATSE's GRBs was then confirmed by several other articles of the author and his collaborators (Balázs, Mészáros, Horváth, & Vavrek (1999), Mészáros, Bagoly, & Vavrek (2000), Vavrek, Balázs, Mészáros, Horváth, & Bagoly (2008)).

Concerning the eventual BATSE's intermediate subclass it was found to be distributed also anisotropically (Mészáros, Bagoly, Horváth, Balázs, & Vavrek (2000)). The distribution is shown on Fig.2.

Concerning the long BATSE's GRBs Mészáros & Štoček (2003) found the distribution to be anisotropic. On the other hand, other statistical tests gave controversial results (Vavrek et al. (2008), see Fig.3).

After Vavrek et al. (2008) the existence of the Gpc structures and thus the breakdown of the Cosmological Principle was declared by Mészáros, Balázs, Bagoly, & Veres (2009) and Mészáros, Balázs, Bagoly, & Veres (2009).

All these 2D studies were based on the BATSE data, because in the BATSE dataset only few GRBs have directly measured redshifts (see, for example, Table 1 of Bagoly et al. (2003)). Hence, 3D tests are not possible with the BATSE data.

4 | OTHER STATISTICAL STUDIES

Řípa & Shafieloo (2017) tested the isotropy of the observed properties of GRBs in the whole Fermi/GBM catalog. It was studied a possibility that at different directions GRBs had different properties such as their durations, fluences, and peak fluxes at various energy bands and timescales. In other words, not the positions of GRBs were tested but their observed astrophysical properties. Later, their method was applied on an updated Fermi/GBM catalog, too, and extended also to the datasets of BATSE and Swift (Řípa & Shafieloo (2019)). The

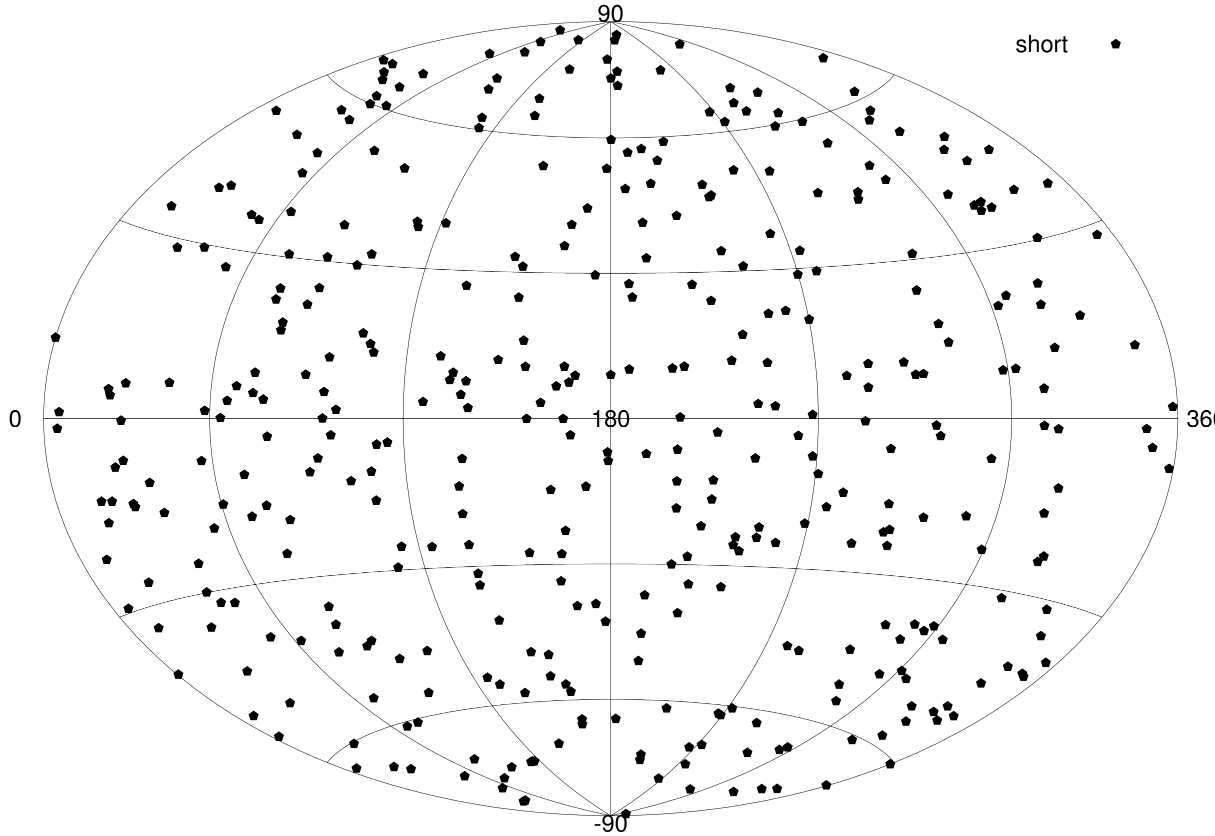

FIGURE 1 The sky distribution of the BATSE's short GRBs in equatorial coordinates.

observed properties of GRBs in all used datasets were found to be consistent with isotropy.

Sokolov et al. (2018) studied the grouping around GRB021004 at $z \simeq 0.56$. A possibility of a galaxy cluster was found.

5 | THREE DIMENSIONAL STUDIES

Only a small fraction of detected GRBs at the gamma-band has measured redshifts from the so called afterglows (either in X-rays, UV, optical, infrared and even at radio band). But for these limited samples the three-dimensional statistical studies are possible.

Using 361 GRBs with measured optical afterglow and redshift, Horváth, Hakkila, & Bagoly (2014) identified a large clustering of GRBs at redshift $z \approx 2$ in the general direction of the constellations of Hercules and Corona Borealis. This angular excess cannot be entirely attributed to known selection biases, making its existence due to chance unlikely. The scale on which the clustering occurs is about $\sim (2-3)\ Gpc$. The underlying distribution of matter - suggested by this cluster - is again big enough to challenge (similarly to the 2D studies mentioned earlier) the standard assumption about the homogeneity and isotropy of the Universe. The position of the structure is shown on Fig.4. The errors are mainly due to the sparse sampling. The χ^2 probability that this clustering is random is $p = 0.051$.

Balázs et al. (2015) (see also Balázs, Rejtő, & Tusnády (2018)) was motivated by a large GRB cluster, and was analyzed the k-th nearest neighbour in the sample further. During the analysis a large regular formation of GRBs was found: the ring is displayed by 9 GRBs with an angular major/minor diameter of $43^o/30^o$ in the $0.78 < z < 0.86$ redshift range, and with a probability of 2×10^{-6} of being the result of a random fluctuation only (Fig.5).

Using the same data Bagoly, Horváth, Hakkila, & Tóth (2015) (see also Bagoly, Rácz, Balázs, Tóth, & Horváth (2016)) reconstructed the empirical sky exposure function with the empirical radial distribution and calculated the general 3D spatial two-point correlation function of the GRBs. Signals of both the large GRB cluster and the ring were identified. There was a third anomaly, caused GRB020819B and GRB050803, at a cosmologically low distance ≈ 56 Mpc from

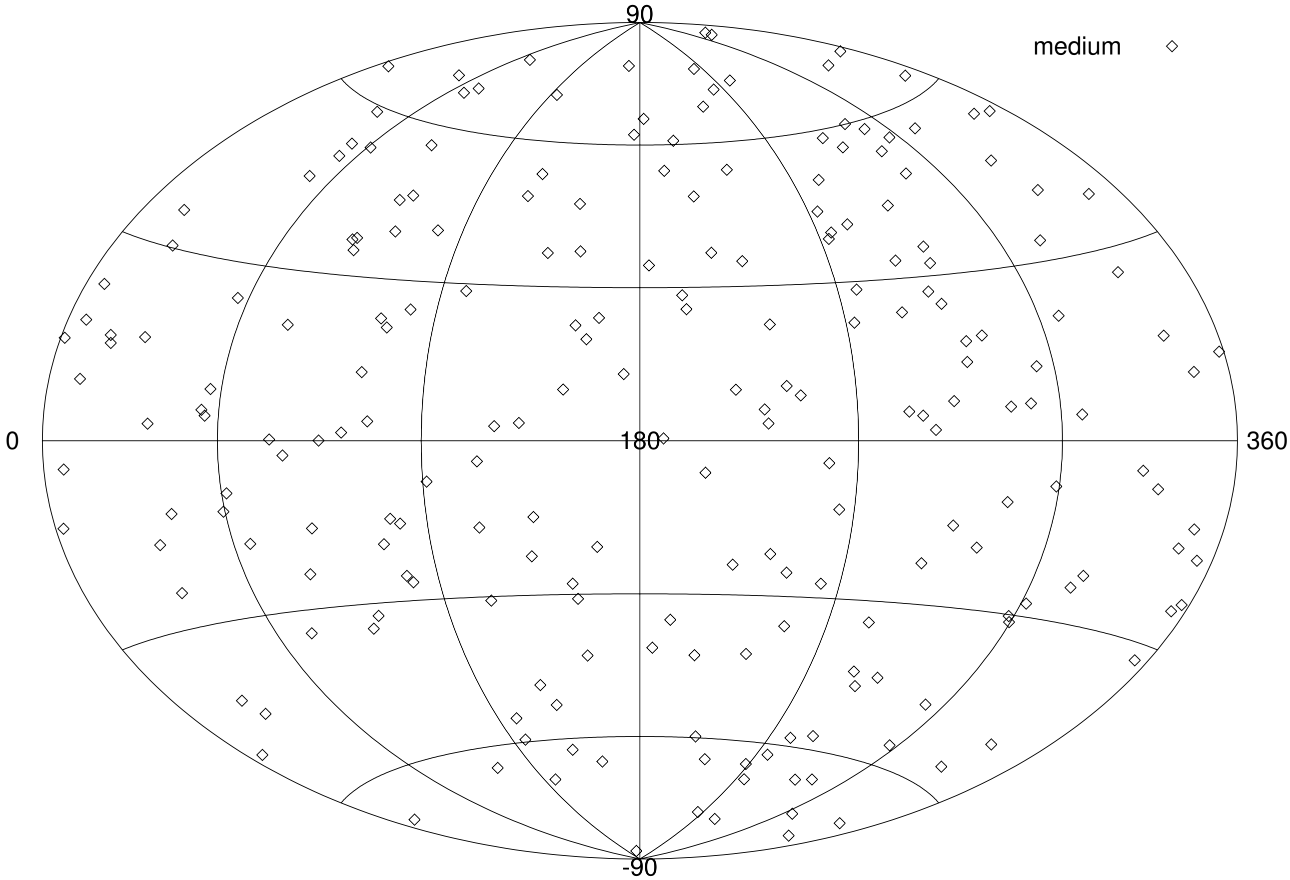

FIGURE 2 The sky distribution of the BATSE's intermediate GRBs in equatorial coordinates.

each other, with a low probability of 0.00996 being a random fluctuation.

6 | CONCLUSION

It can be claimed that the found $\sim$ *Gpc* structures of the spatial distribution of GRBs a high redshifts do not allow an averaging. This results, obtained exclusively from the observations, is at a strong contradiction with The Cosmological Principle requiring a transition scale of homogenity.

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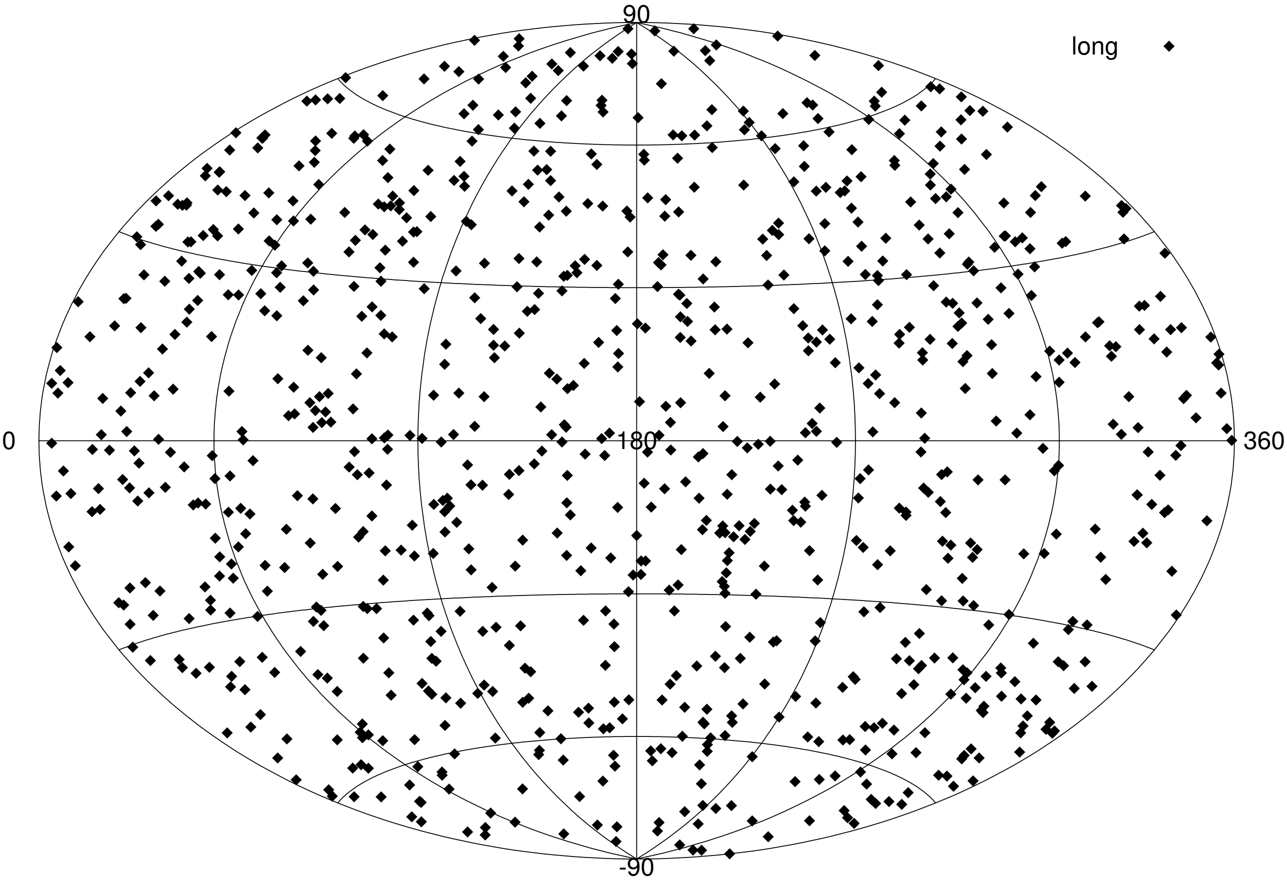

FIGURE 3 The sky distribution of the BATSE's long GRBs in equatorial coordinates.

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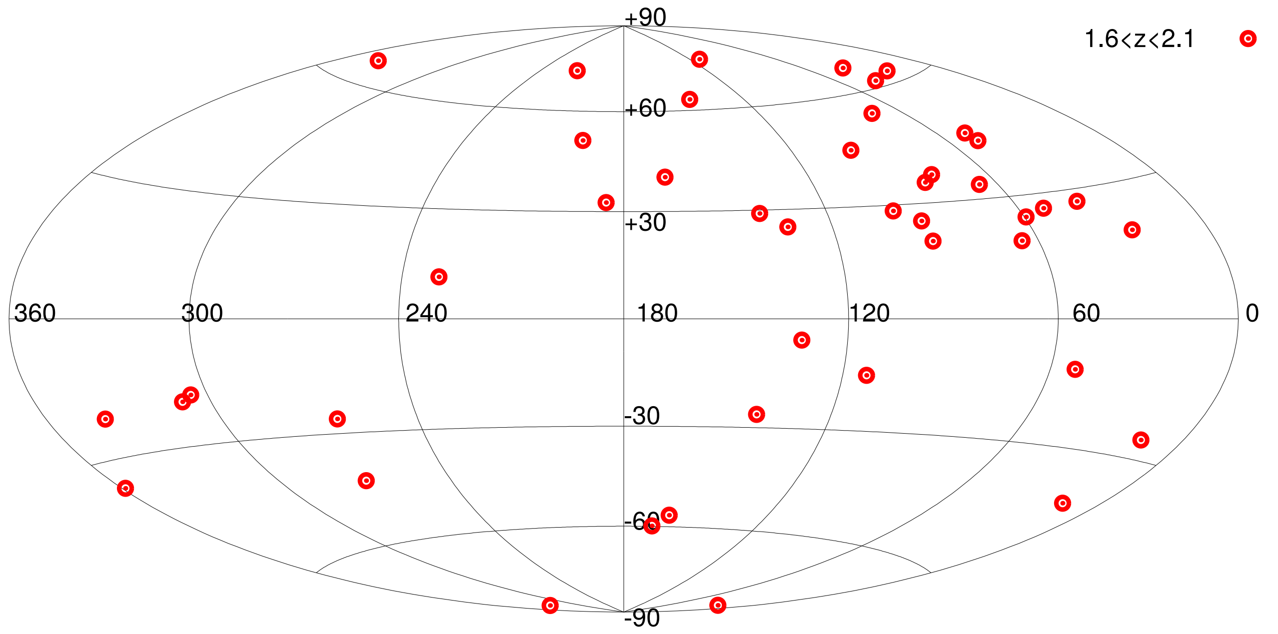

FIGURE 4 The distribution of GRBs in the redshift range $1.6 < z \leq 2.1$ at Galactical coordinates. The cluster direction is at approx $l = 88^o, b = 63^o$.

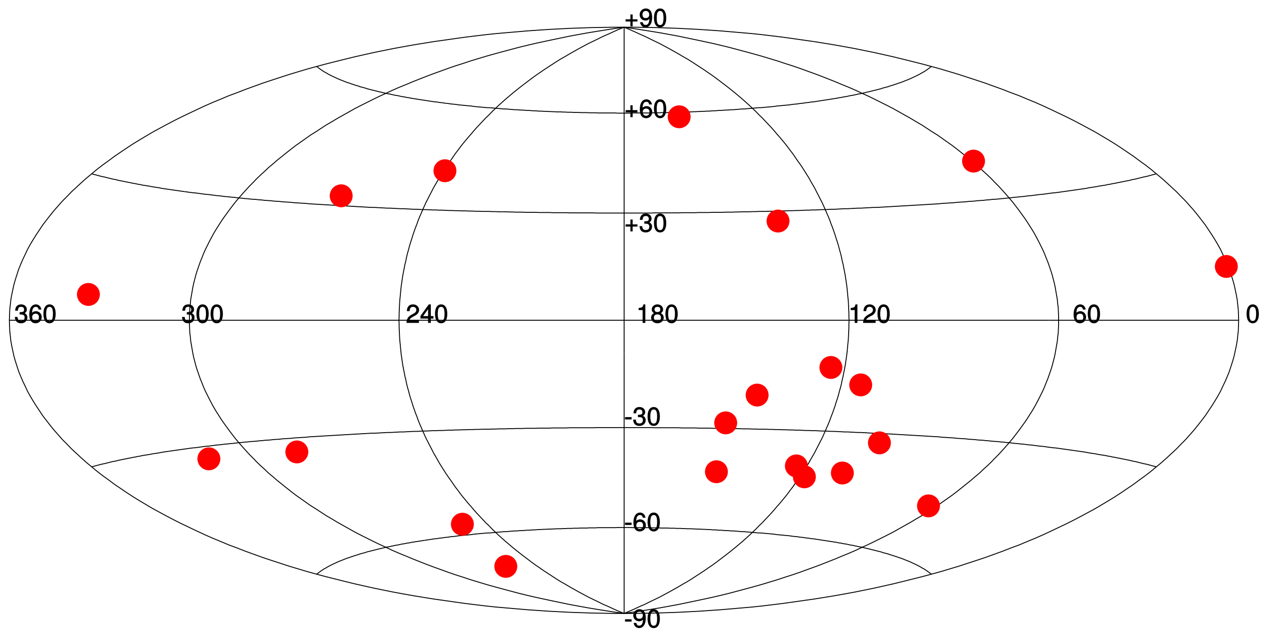

FIGURE 5 Angular distribution of GRBs in Galactical coordinates.The ring-like structure of objects is in the lower right part of the frames.

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