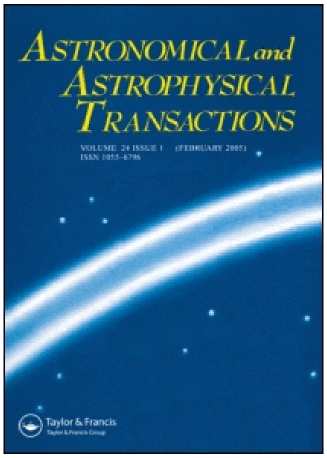

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DOES THE ANGULAR CORRELATION FUNCTION OF GRBs CONFIRM THEIR COSMOLOGICAL NATURE?

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According to the location on the celestial sphere of the objects of different types, two-point angular correlation functions $W(\vartheta)$ are calculated for:

(1) 458 gamma-ray bursts (GRB) with $\vartheta = 6°$ step in the angle range from 0° to 180° and with $\vartheta = 2°$ in the range from 0° to 60°;

(2) 413 unresolved extragalactic radio sources (QSO, BL Lac, radiogalaxies) from a sample used for astrometric system of coordinates obtained with to VLBI with 6° step in the angle range from 0° to 180°;

(3) 330 unresolved radio sources from the same sample but without taking into account the objects located near the Galactic plane ($b^{II} = \pm 20°$) with 2° step in the angle range from 0° to 60°;

The $W(\vartheta)$ functions obtained show that:

(1) for GRB, $W(\vartheta)$ correlation function does not differ from a random distribution in the whole range of angles at the 3σ significance level;

(2) for unresolved radio sources with $\vartheta < 18°$ (for the whole sample) and with $\vartheta < 4°$ (for the sample without the band $b^{II} = \pm 20°$), $W(\vartheta)$ significantly differs from a random distribution (at the level $> 3\sigma$) and resembles the $W(\vartheta)$ function obtained for clusters of galaxies. A comparison of angular two-point correlation functions obtained for GRB and extragalactic compact radio sources brings to a conclusion that GRB do not belong to a normal population of galaxies with $Z < 1.5$.

I. It was almost 20 years ago when the VELA satellite discovered the first cosmic gamma-ray bursts (GRB) in the 10^2–10^4 keV energy range. Nevertheless, the nature of these objects has not been clarified so far. Hypotheses concerning the origin of GRB differ very much, they change from a near-Sun location (Kuznetsov, 1982), to a cosmological one (Usov and Chibisov, 1986). This can be explained by the fact that at present there is only one reliable identification of a strong GRB, detected on March 5, 1979 in the N49 nebula which is a supernova remnant in the LMC. Even this identification leaves many questions unclarified. All other attempts to identify a GRB with any optical, radio, X-ray, gamma and IR objects turned out to be unsuccessful. After the launch of the Compton GRO in April 1991, the number of GRB detected at an accuracy from a fraction of degree to 25° has achieved approximately 500. In spite of that, the problem of GRB identification remains in the same state. It reminds a situation with radio pulsars, the percentage of

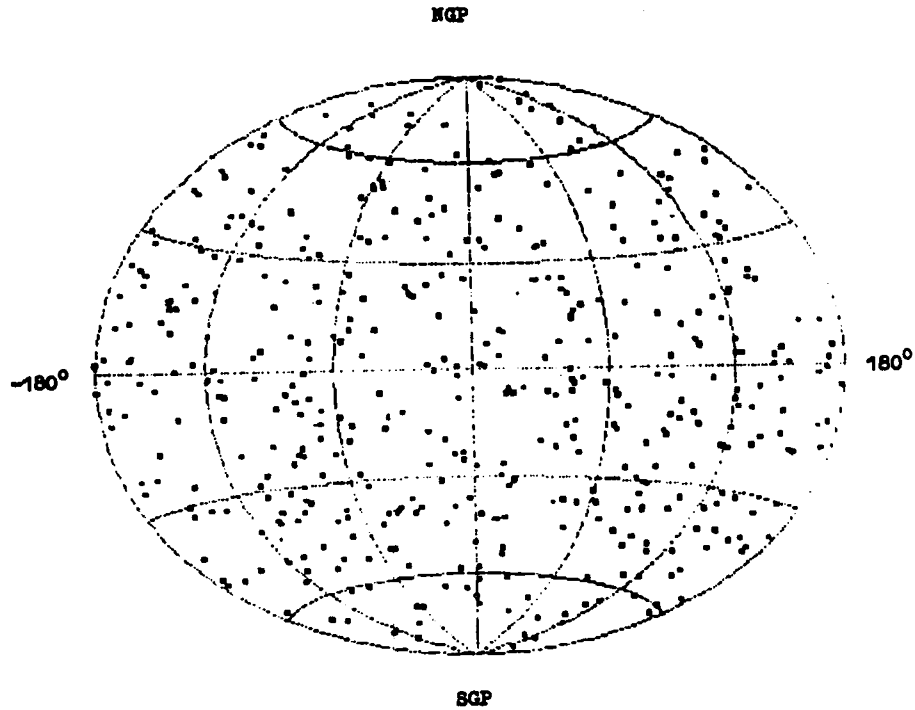

Figure 1 Distribution of 458 gamma bursts over the celestial sphere in the Galactic coordinates. 260 of them were detected by the BASTE instrument onboard the GRO satellite and 198 were taken from earlier data obtained by different authors.

their identification with optical objects being extremely small. GRB seem to be evolutionary correlated with neutron stars. There are two evidences in favor of this suggestion: three GRBs have periodic intensity variations with periods from 2 to 8 seconds and their brightness curves show short maxima and minima with typical periods of several milliseconds.

One of surprizing characteristics of GRBs is a large degree of isotropy and homogeneity of their distribution over the celestial sphere (Figure 1). It radically differs from the distribution of radio pulsars which are significantly concentrated to the Galactic plane.

Values given below can illustrate the isotropy of the GRB distribution. These values characterize dipole and quadrupole concentration, they were obtained by using data for 458 bursts for which the following coordinates were found in papers published:

$$\langle \sin b^{II} \rangle = -0.0043, \quad \langle \sin^2 b^{II} \rangle = 0.310, \quad \langle l^{II} = 0.^{\circ}4 \rangle$$

(for an ideally isotropic distribution, these values should be equal to 0, 0.333 and 0° respectively).

$$\frac{N_{(\text{North hemisphere})}}{N_{(\text{South hemisphere})}} = 0.846$$

$$\frac{N_{(\text{Galactic center hemisphere})}}{N_{(\text{anticenter hemisphere})}} = 0.957$$

(the values corresponding to an isotropic distribution should be equal to 1).

We have not discovered higher recurrency as well. To perform this analysis, we devided the celestial sphere into 16 equal areas, an average number of objects being about 25 in each area. Then a number of objects in each of the 16 areas was compared with that for an isotropic distribution by using the χ^2 method. For 15 degrees of freedom, a homogeneous distribution hypothesis is confirmed at a 0.8 confidence level. For comparison, different computer simulations of homogeneous distribution give a 0.9–0.85 confidence level ($\chi^2 = 10$).

Data obtained by Pioner Venus Orbiter (PVO) in the 100–200 keV band also favor a GRB homogeneous distribution:

$$N_{\mathrm{GRB}}(> F) = 30\,\mathrm{year}^{-1} \times \left[F \frac{\mathrm{erg}}{\mathrm{cm}^2\,\mathrm{s}} / 2 \times 10^{-5}\right]^{-1.48}$$

This corresponds to $n = \frac{3}{2}$, which is a power index in the (log N–log S) dependence for rather intense bursts ($F > 10^{-5}$ erg/cm^2 s). However, for more numerous weak bursts (with $F < 5 \times 10^{-6}$ erg/cm^2 s) detected by the BATSE instrument aboard the GRO satellite, a slope of the (log N–log S) curve becomes significantly flatter ($n \approx 0.6$) (Paczynsky, 1992). If fluxes remain isotropic in all energy ranges, this can confirm the observed form of the GRB luminosity function (Wasserman, 1992). At the same time, it should be mentioned that there are some allusions to a possible inhomogeneity of the GRB distribution (Band, 1992).

When GRBs were discovered, an evolutional correlation between old neutron stars and GRB was immediately suggested (Madau, 1990; Shaefer, 1990; Bisnovatyi-Kogan and Chechetkin, 1981; Komberg, 1983; Bisnovatyi-Kogan and Illarionov, 1989). This conclusion was based on both some observational facts (such as the impossibility to identify them with optical objects and periods of rotation appropriate for neutron stars) and some theoretical considerations. However, a number of other hypotheses were suggested. According to one of them, GRBs are located in an extended halo (hundreds of kiloparsecs in radius) of the Galaxy (Shklovsky and Mitrofanov, 1985) This hypothesis was recently widely discussed from the theoretical point of view (Salpeter and Wasserman, 1992; Hattori and Terasawa, 1993; Gurevich *et al.*, 1993). At the same time, there are several important objections against it. There is no higher GRB concentration in near the halos of M31, LMC and SMC. This is the main point for these objections (one can find a discussion of this problem in Li and Liang, 1992).

A possibility of a cosmological nature of GRBs was also discussed. The first who proposed such an explanation were Usov and Chibisov (1975). They proceeds from a wrong (as it is evident now) interpretation of (log N–log S) dependence which had been found for a small number of intense GRBs by that time. Recently, Paczynski

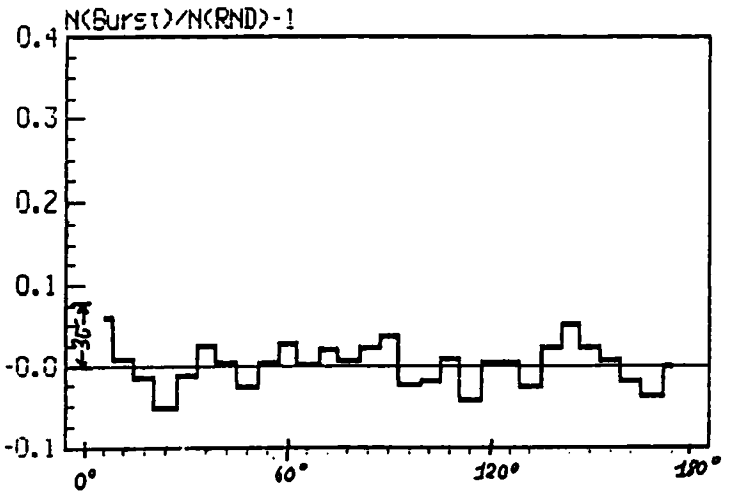

Figure 2 Two-point angular correlation function calculated from the distribution of 458 gamma bursts (Figure 1).

developed this idea further (Paczynski, 1986, 1992; Narayan *et al.*, 1992). It is based on an extreme rarity of two neutron star mergers in distant galaxies ($Z > 1$). Active nuclei of galaxies were also proposed as cosmological sources of GRBs (Prilutski and Usov, 1975).

Our purpose is not a rejection of the hypothesis of the cosmological nature of GRBs on the basis of one or another theoretical assumption. We attempt to analyze this hypothesis by comparison of the two-point angular correlation function $W(\vartheta)$ derived from the locations of GRBs and some extragalactic objects on the celestial sphere.

As follows from numerous investigations, extragalactic objects are not distributed chaotically over the celestial sphere, but they belong to a so-called "large-scale structure". In order to analyze this structure, the method of correlation functions was proposed. It was used for both unidentified objects ($W(\vartheta)$, the angular correlation function) and identified objects with distance known ($\xi(r)$, the spatial correlation function). Here, we can use only the $W(\vartheta)$ † function which was derived by different authors for galaxies (Gott and Turner, 1979; Maddok *et al.*, 1990) and clusters of galaxies (Bahcall and Soniera, 1983; Bahcall *et al.*, 1988). The correlation angle ϑ_0 at which $W(\vartheta) = 1$ may serve as a characteristic of the object's clustering scale. For a sample of galaxies with $m_{pg} < 15^m$, this turns out to be

†

$$W(\vartheta) = \frac{N_{\text{observed}}(\vartheta)}{N_{\text{random}}(\vartheta)} - 1,$$

where N_{observed} is an observed number of object pairs in a given area, an angle between them being ϑ. $N_{\text{random}}(\vartheta)$ is a number of binary objects in the same area with the same angle ϑ between them in the case of their random distribution with the same surface density. The latter is obtained using a generator of random numbers.

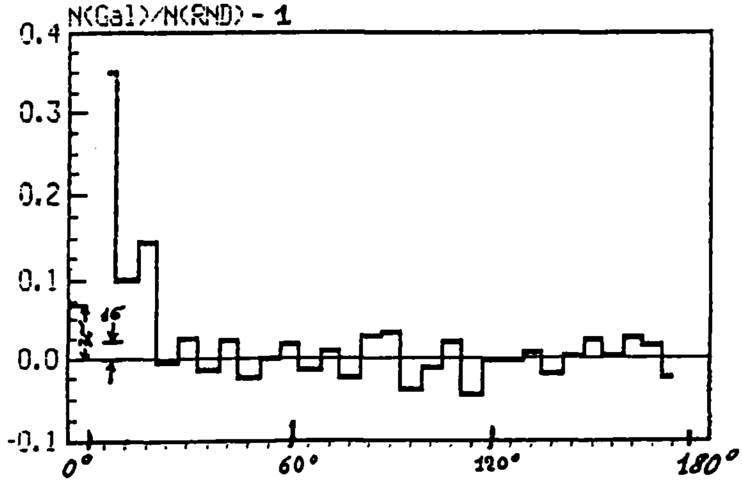

Figure 3 Two-point angular correlation function calculated from the distribution of 413 compact radio sources (Figure 4).

$\vartheta_0 \simeq 1°$ and $\vartheta_0 \simeq 5°$ for a sample of galaxy clusters with a $R > 1$ richness. Moreover the amplitude of the correlation function (and ϑ_0 consequently) increases with the depth of the sample (i.e., with m_{pg}) and with cluster richness. Thus, if GRBs belong to a normal galactic population, this should affect the form of the GRB correlation function. We have obtained the result expected.

II. For 458 GRBs observed with an accuracy better than several degrees, we plotted $W(\vartheta)$ with a 6° step in the range from 0° to 180° (Figure 2). One can see that, at a 3σ level, the GRB distribution observed on the celestial sphere does not differ from a random one. Hence, one can conclude that GRBs cannot belong a normal population of galaxies, whose distribution on the celestial sphere is not random.

For comparison, Figure 3 presents $W(\vartheta)$ which we obtained for the distribution of 413 distant point radio sources over the celestial sphere (Figure 4) selected for the astrometric VLBI coordinate system (Chr. De Vegt, 1992). It can be seen that the amplitude of a correlation function significantly exceeds the 3σ level in the angle range $\vartheta < 16°$, i.e., the distribution of point radio sources (radiogalaxies, QSO and BL Lac type objects) is not random [‡] This result is not unexpected because all these objects are associated with nuclei of massive galaxies located in central parts of clusters or groups of galaxies. $W(\vartheta)$ presented in Figure 3 seems to be a convincing argument. (This function was given by Romani and Dan Maoz (1993) for 1551 Abell clusters, among them there were 546 galaxies located in the central regions of these clusters of galaxies). Thus, to

[‡]For comparison, Figure 5 shows a two-point angular correlation function for 330 point radio sources from the same sample (Figure 4) but without objects located near the Galactic plane ($b^{II} = \pm 20°$).

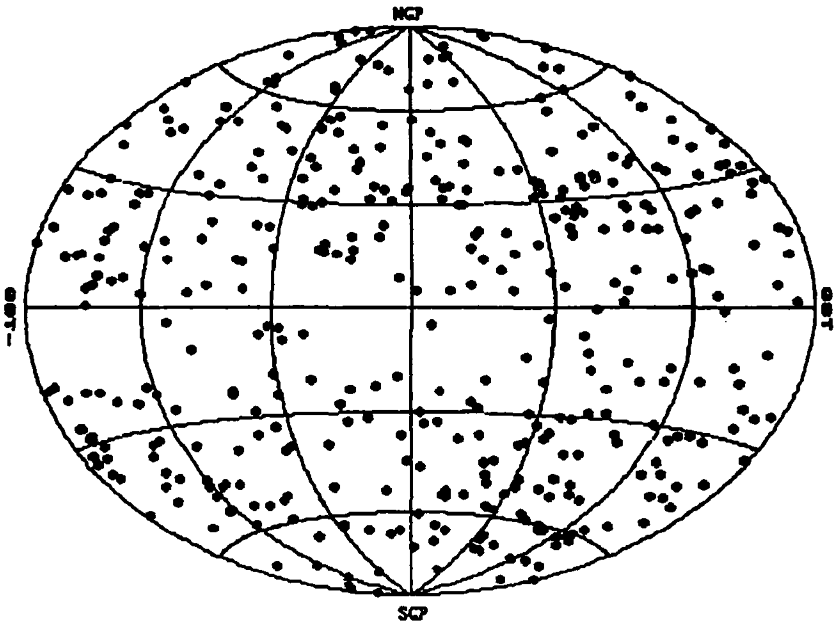

Figure 4 Distribution of 413 extragalactic compact radio sources (nuclei of galaxies, QSO and BL Lac type objects) over the celestial sphere in the Galactic coordinates.

our opinion, the data given above evidence against the cosmological hypothesis for the GRB nature. But there are two things to note concerning this conclusion.

First, the amplitude of the QSO clustering does not differ from a random one for $Z > 1.5$ with Z the redshift (Chu and Zhu, 1988; Sheiver, 1987) as it was shown for correlation function of QSO. Thus there is a theoretical possibility that GRBs, like QSOs, may correlate with very distant cosmological objects.

Second, there are indications that correlation characteristics of faint galaxies correspond to a weaker clustering (Pritchett and Infante, 1992). Thus, our conclusions may be disputed if GRB sources are located in dwarf galaxies alone (e.g., Narayan *et al.*, 1992).

A question whether the nature of cosmic GRBs is Galactic or extragalactic remains the key problem of this outstanding phenomenon. We believe that it can be solved with the help of observations of GRB spectra in the soft X-ray range from 3 to 0.1 keV as was proposed by N. S. Kardashev. If GRBs have an extragalactic origin, the cut-off energy must depend only on the galactic coordinates of each gamma-ray burst observed. The number of absorbing atoms in the Galaxy for any point on the celestial sphere with the Galactic coordinates known is well studied due to radioobservations in the λ 21 cm hydrogen line. In this case there should be no correlation between the cut-off energy and intensity of bursts observed. According to model simulations, the cut-off energy depends very in-

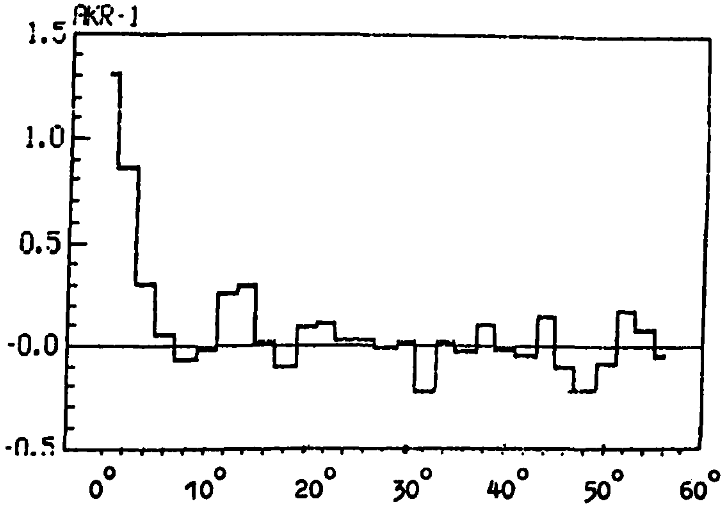

Figure 5 Two-points angular correlation function for 330 radio sources excluding the objects located in the Galactic latitude band $|b^{II}| < 20°$.

significantly on the spectrum of a burst, at least for power-law spectra with index varying from −1 to −3 (these very values are observed in the energy range above 10 KeV).

We propose to develop equipment with detector area more than 100 cm^2 and field of view of no less then a half of the celestial sphere and to perform an experiment in this energy range ($E <$ 1–3 KeV) which is very difficult for observations. This would probably allow observations of GRBs with fluxes exceeding 10^{-6} erg/cm^2 s.

During six months of observations one can hope to obtain spectral data for several dozens of bursts which is quite enough for our purposes because a half of the bursts will be located in the band with galactic latitude less than 30°.

In addition, we would like to make an important note. All the data from which we obtained the two-point angular correlation function were obtained with different values of coordinate error boxes. Data errors for the BATSE instrument onboard the GRO satellite exhibit a wide scatter from 0°.5 to 25°. Error boxes for gamma bursts whose coordinates were obtained by the time delay method from several spacecrafts measurements were significantly smaller being at a level of several arc minutes and sometimes even better. It is not clear how these errors varying by two orders can influence the angular correlation function for GRBs.

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References

Bahcall, N. A., Bataski, D. J., and Olwin, R.P. (1988) *Astrophys. J. Lett.* **333**, L13.
Bahcall, N. A. and Soneira, R. M. *Astrophys. J.* (1983) **270**, 20.
Band, D. (1992) *Astrophys. J. Lett.* **400**, L63.
Bisnovatyi–Kogan, G. S. and Chechetkin, V. M. (1981) *Astronom. Zhur. USSR* **58**, 561.
Bisnovatyi–Kogan, G. S. and Illarionov, A. F. (1989) *Astron. & Astrophys.* **213**, 107.
Chu, Y. and Zhu, X. (1988) *Astron. & Astrophys.* **205**, 1, 1.
Gott, J. R. and Turner, E. L. (1979) *Astrophys. J. Lett.* **232**, L79.
Gurevich, A. V., Beskin, V. S., Zybin, K. P., and Ptitsyn, M. O. *ZETP* (to be published).
Hattori, M. and Terasawa, N. (1993) *Pr. RIKEN IPSR-SR* **57**.
Hurley, K. (1993) *Private communications.*
Klebesadel, R. W., Strong, I. B., and Olson, R. A. (1973) *Astrophys, J. Lett.* **182**, L85.
Komberg, B. V. (1983) *Proceedings of the Space Research Inst.*, Moscow, "Nauka", p. 30.
Kuznetsov, A. V. (1982) *Cosmic Research* **20**, 72.
Li, H. and Liang, E.P. (1992) *Astrophys. J. Lett.* **400**, L59.
Madau, P. (1990) *Proceedings of Los-Alamos Workshop*, p. 9.
Maddok, S. J. *et al.* (1990) *MNRAS* **242**, 43.
Narayan, R., Paczynski, B., and Piran, T. (1992) *Astrophys. J. Lett.* **395**, L83.
Paczynski, B. (1986) *Astrophys. J. Lett.* **389**, L43.
Paczynski, B. (1992) *POP-463*; *Science* (to be published).
Prilutski, O. F. and Usov, V. V. (1975) *Aph. Sp. Sc.* **34**, 395.
Pritchett, C. J. and Infante, L. (1992) *Astrophys. J. Lett.* **399**, L35.
Romani, R. W. and Maoz, D. (1992) *Astrophys. J.* **386**, 3.
Salpeter, E. E. and Wasserman, I. (1992) *Pr. Cornell Univ.* No. 100.
Shaeffer, B. E. (1990) *Proceedings of Los-Alamos Workshop*, p.107.
Shaeffer, B. E. (1993) *Private communications.*
Shaver, P. A. (1987) *ESO Pr.* No. 534.
Shklovsky, I. S. and Mitrofanov, I. G. (1985) *MNRAS* **212**, 545.
Usov, V. V. and Chibisov, G. V. (1975) *Soviet Astron.* **19**, 115.
De Vegt, Chr. (1992) *The Messenger* **69**, 28.
Wasserman, I. (1992) *Astrophys. J.* **394**, 565.