

Evidence for gamma-ray bursts originating within 11 Mpc

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Abstract. We investigate the number of gamma-ray bursts in two particular strips of the sky using the data in 3B catalog of Burst and Transient Source Experiment (BATSE). One stripe is related to the plane in which the intergalactic globular clusters ($R > 25\text{kpc}$) and Galactic satellite galaxies ($45\text{kpc} < R < 280\text{kpc}$) concentrate, the other is concerned to nearby galaxies ($1\text{Mpc} < R < 11\text{Mpc}$). We find that the density of GRBs in these two strips is higher than that in other parts of the sky with significance 2.8 and 1.9σ respectively. We also compare the peak flux distribution of GRBs in these two stripes with that in other parts of the sky, and find no difference in the former stripe but a difference in the latter with a significant level $\alpha = 0.05$. This is consistent with the distance scales of these two planes. So it suggests that at least a substantial fraction of GRBs may be related to those objects in these two planes and thus originate within 11 Mpc.

Key words: gamma-rays: bursts

1. Introduction

Gamma-ray bursts (GRBs) have been discovered for more than twenty years, but their distances are still unknown. The spatial distribution pattern is a major clue to their origin. More than one thousand GRBs have been detected by the Burst and Transient Source Experiment (BATSE) on the Compton Gamma-ray Observatory (CGRO). However, their locations are still consistent with large-scale isotropy (Briggs et al. 1996). One possible reason is that GRBs originate at cosmological distances (Prilutski & Usov 1975; Woods & Loeb 1994; Paczynski & Xu 1994). However, many authors insist that GRBs may originate from a Galactic halo (Fishman 1979; Jennings 1982; Brainerd 1992;) or Galactic disk plus halo (Smith & Lamb 1993). Scharf (1995) have found some evidence for a local origin of the GRBs in fluence- and number-weighted dipoles measurement.

If GRBs are cosmological, their spatial distribution should be isotropic. However, the intergalactic globular clusters ($R > 25\text{kpc}$) and Galactic satellite galaxies ($45\text{kpc} < R < 280\text{kpc}$), and nearby galaxies ($1\text{Mpc} < R < 11\text{Mpc}$) concentrate towards

respective planes. Therefore, if a substantial fraction of GRBs are related to these objects, the spatial distribution of GRBs may deviate slightly from isotropy, i.e. the density of GRBs may be higher in these planes than in other parts of the sky. Furthermore, since the possible objects in different planes have different distance scales, the excess of GRBs should mostly exist in the respective distance scale and this may affect the peak flux distribution of GRBs.

We introduce these two planes in Sect. 2, and in Sect. 3 we analyze the spatial distribution of GRBs in the 3B catalog of the Burst and Transient Source Experiment (BATSE). The result shows that GRBs concentrate towards these two planes. Their distributions of peak flux are consistent with the distance scales of these two planes. Then we calculate the probability of coincidence and give the significant level. We give some discussion and draw the conclusion which suggests that at least a substantial fraction of GRBs may be not cosmological (Sect. 4).

2. The Magellanic Group plane and the nearby galaxies plane

Many objects usually concentrate towards a certain plane. In this paper we are interested in two of them. The first plane is related to the nearby ($25\text{kpc} < R < 280\text{kpc}$) dwarf galaxies and intergalactic globular clusters (Majewski 1994; Schmidt 1992, 1993). There is reasonable possibility that some of them may be tidal debris of the Magellanic Clouds (Kunkel 1976; Lin 1993). They seem to concentrate towards the orbital plane named the Magellanic Group plane (the MG-plane) (see Fig. 1). The normal to this plane points to the direction $(l, b) = (169^\circ, -23^\circ)$ (Kunkel 1976). If GRBs are related to these objects, they will show some concentration towards the MG-plane. In another case, if GRBs are related to an extended Galactic halo of primordial objects, these primordial objects may also concentrate towards the MG-plane by the gravitational perturbation (Maoz 1993). The nearby galaxies ($1\text{Mpc} < R < 11\text{Mpc}$) seem to concentrate towards another plane. We may call it the nearby galaxies plane (the NG-plane). The majority of the nearby galaxies are situated around this plane whose normal direction points approximately to $(l, b) = (47^\circ, 3^\circ)$. Fig. 2 shows the distribution of these 243 nearby galaxies (Schmidt 1992, 1993).

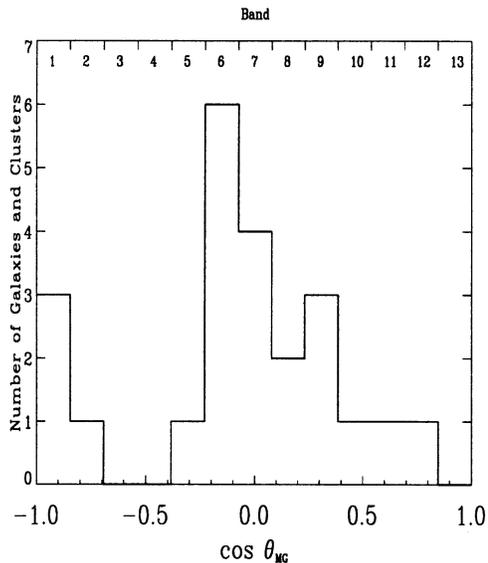


Fig. 1. The spatial distribution of nearby satellite galaxies and clusters with $25\text{kpc} < R < 280\text{kpc}$. The whole sky has been divided into 13 bands along the normal direction of the MG-plane. Each band has an equal area. θ_{MG} is the angle between a point and the normal direction of the the MG-plane $(l, b) = (169^\circ, -23^\circ)$.

If GRBs are related to those objects mentioned above, they may concentrate towards these two planes.

3. Analysis of the observational data

The statistics $\langle \sin^2 b - 1/3 \rangle$ is often used to test the concentration towards the Galactic plane. Maoz (1993) used another similar statistics $\langle \cos^2 b_{plane} \rangle$ to determine the concentration towards other particular planes, where b_{plane} is the angular distance to the interested plane. He found that the value of $\langle \cos^2 b_{plane} \rangle$ had an increase of $1-2\sigma$ for the MG-plane by using BATSE data before March 1992 (241 bursts). These statistical methods are powerful to test the quadrupole moment. They have some advantages. For example, they do not need to bin the data. But in our case we are only interested in whether the density of GRBs in these planes is higher than that in other parts of the sky. It is not equivalent to the quadrupole moment, because, for example, a concentration towards both disk and poles may not be detected by these quadrupole moment statistics. Moreover, if we want to detect the enhancement in more than one plane, these statistics will be ineffective. We can simply divide the whole sky into three parts due to the physical reasons which will be discussed below. Two of them (selected area) consist of the interested plane and the last one (unselected area) does not. We can count the GRBs in each part, compare the counts in each selected area with that in the unselected area and calculate the corresponding probability of coincidence. According to Fig. 1, it is reasonable to select band 6,7,8 and 9 as selected area since they contain about 65% of the total galaxies and clusters with only 30% of the sky region. For the NG-plane we select band 10,11 and 12 according to Fig. 2. In prac-

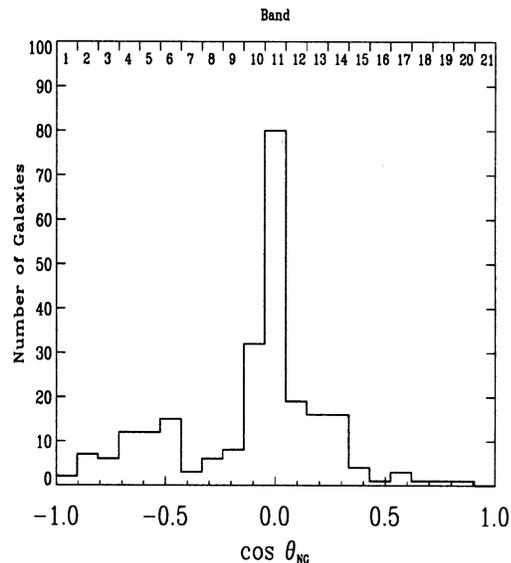


Fig. 2. The distribution of nearby 243 galaxies with a distance $1\text{Mpc} < R < 11\text{Mpc}$. The whole sky has been divided into 21 bands along the normal direction of the NG-plane. Each band has an equal area. θ_{NG} is the angle between a point and the normal direction of the the NG-plane $(l, b) = (47^\circ, 3^\circ)$.

tice, we let $-0.2 < \cos \theta_{MG} < 0.4$ for the MG-plane and $-0.12 < \cos \theta_{NG} < 0.12$ for the NG-plane. These two stripes is our selected area, and we call them Area 1 and Area 2 respectively. The unselected area is called Area 3 (see Fig. 3). Notice there is an overlap between Area 1 and Area 2. Below we will make some test to investigate the concentration in Area 1 and Area 2 respectively. The null hypothesis is that the distribution of GRBs is isotropy.

3.1. Density and peak flux distribution in the MG-plane

Now we compare the counts of GRBs in Area 1 (MG-plane) with that in Area 3 (unselected area). The total number of bursts in Area 1 and Area 3 is $n = 995$ in the 3B catalog. The number of bursts in Area 1 is $m = 382$. If BATSE's sky exposure is considered here, the normalized equivalent area of Area i is

$$s'_i = \int_{s_i} t(s) ds / \int_{s_0} t(s) ds, \quad (1)$$

where $t(s)$ is the exposure time adopted from the first BATSE catalog (Fishman et al. 1994), s_0 is the total area of whole sphere and assumed to be 1. After sky exposure correction, the areas of Area 1 and Area 3 are $s'_1 = 0.308$ and $s'_3 = 0.596$ respectively obtained from Monte Carlo calculation. We assume the distribution of GRBs is isotropy, thus the number of GRBs in Area 1 and Area 3 will follow the binomial distribution. Therefore, the probability of coincidence is

$$p = \sum_{i=m}^n C_n^i s_p^i (1 - s_p)^{(n-i)}, \quad (2)$$

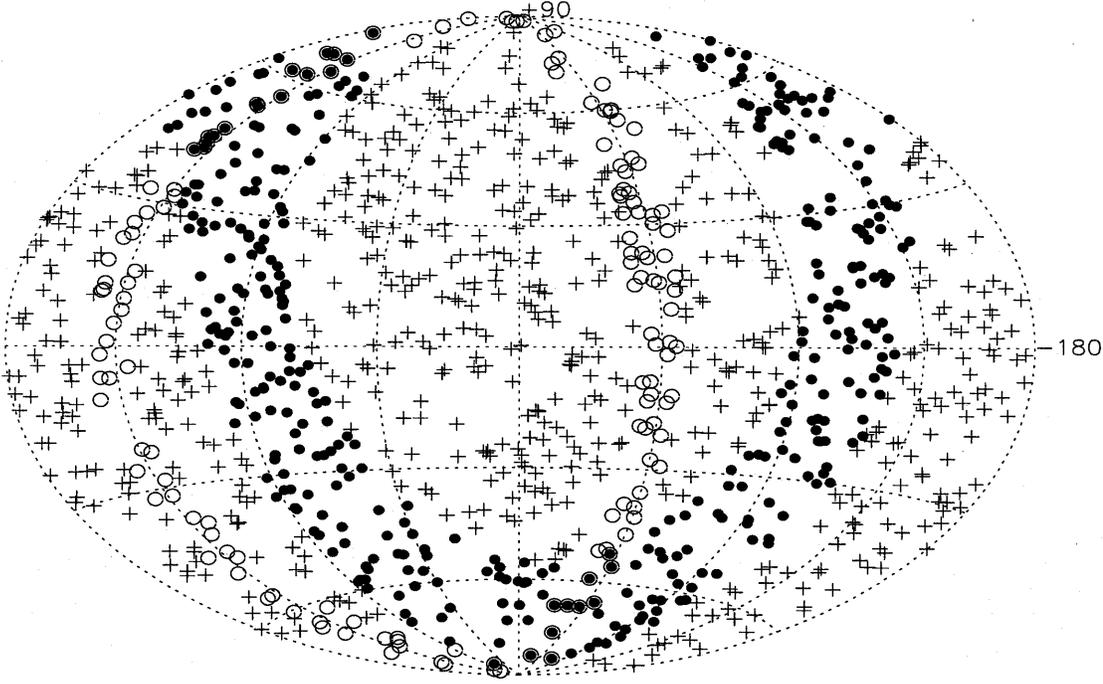


Fig. 3. The Aitoff projection map of GRBs. The filled circles represents the GRBs in Area 1 (MG-plane), the open circles Area 2 (NG-plane) and the cross Area 3 (unselected area). The 27 filled plus open circles represents the overlap. The total number of GRBs is 1122.

where $s_p = s'_1 / (s'_1 + s'_3)$. Then we get $p = 2.4 \times 10^{-3}$ (2.8σ). The detail is presented in Table 1 and Fig. 4. So we can conclude that the density of GRBs in Area 1 (MG-plane) is higher than that in Area 3 (unselected area) with a significance 2.8σ .

Now we further investigate the peak flux distribution of GRBs in the MG-plane (see the top one of Fig. 5). Here we use one-sided Mann-Whitney U-test (Mann et al. 1947) to test whether the peak flux distribution in Area 1 is fainter than that in Area 3. The Mann-Whitney U-test is a widely used nonparametric test for difference between two independent samples. We combine the GRBs in Area 1 and Area 3, and array them according to their peak flux (1024 ms). Then we assign ranks to them, starting with 1 for the brightest one and n for the n th. We calculate the sum of the ranks in Area 1 ΣR_1 and the significance

$$t_s = (U_1 - n_1 n_3 / 2) / \sqrt{n_1 n_3 (n_1 + n_3 + 1) / 12}, \quad (3)$$

where $U_1 = n_1 n_3 + n_1 (n_1 + 1) / 2 - \Sigma R_1$, and n_1 and n_3 are the number of GRBs in Area 1 and Area 3 respectively. t_s is proved to obey the t distribution. We get $t_s = 0.58 < t_{\alpha=0.05} = 1.65$, where $t_{\alpha=0.05}$ is the critical value of the t distribution with a significant level $\alpha = 0.05$. The result shows that we can not conclude that the peak flux distribution in Area 1 is fainter than that in Area 3 (see Table 2).

3.2. Density and peak flux distribution in the NG-plane

We adopt the similar test as in Sect. 3.1 to the NG-plane. Here we only give the results, for detail see Table 1,3 and Fig. 4. The number of GRBs in Area 2 is $m = 154$ and $s'_2 = 0.125$, Then we get $p = 2.7 \times 10^{-2}$ (1.9σ) and conclude that the density

Table 2. The one-sided Mann-Whitney U-test of the peak flux distribution in the MG-plane

Plane	i	n_i	ΣR_i	U_i
Area 1 (MG-plane)	1	285	111462	67233
Area 3 (unselected)	3	484	184603	70707

$$t_s = (U_1 - n_1 n_3 / 2) / \sqrt{n_1 n_3 (n_1 + n_3 + 1) / 12} = 0.58$$

Note: $U_1 = n_1 n_3 + n_1 (n_1 + 1) / 2 - \Sigma R_1$,

$t_{\alpha=0.05} = 1.65$, where t_{α} is the critical value of the t distribution with a significant level α .

of gamma-ray bursts in the NG-plane (Area 2) is higher than that in unselected area (Area 3) with a significance 1.9σ (see Table 1).

The peak flux distribution of GRBs in the NG-plane is shown in Fig. 5 (bottom). Since the distances of nearby galaxies in the NG-plane are much greater than that of the Galactic halo, we can predict the peak flux of them will be less than that in Area 3. So we use one-sided Mann-Whitney U-test here. The null hypothesis H_0 is: The peak flux distribution in Area 2 is the same as that in Area 3. The alternatives hypothesis H_1 is: The GRBs in Area 2 is fainter than that in Area 3. We get $t_s = 1.69 > t_{\alpha=0.05} = 1.65$, so we conclude the peak flux of the GRBs in Area 2 is fainter than that in Area 3 with a significant level $\alpha = 0.05$ (see Table 3).

Table 1. The number of GRBs in each Area

Plane	s	s'	n	m	M	p	Significance (σ)
Area 1 (MG-plane)	0.300	0.308	995	382	345.6	2.4×10^{-3}	2.8
Area 2 (NG-plane)	0.120	0.125	767	154	140.3	2.7×10^{-2}	1.9
Area 3 (unselected)	0.609	0.596	-	613	668.7	-	-

Note: M is the expected number. $M = 1122 \times s'$.

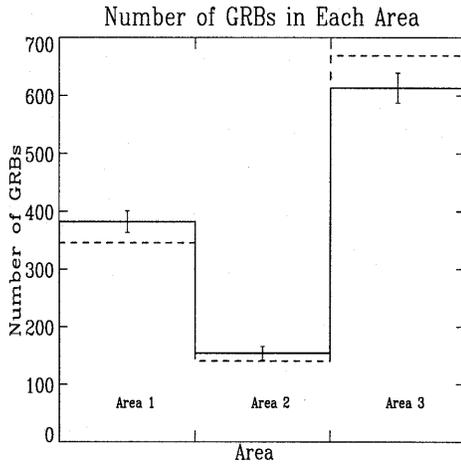


Fig. 4. The Number of GRBs in Each Area. The solid lines represent the number of GRBs in each area and the dashed lines the expected number (see Table 1). The error bar represents $\pm 1\sigma$.

Table 3. The one-sided Mann-Whitney U-test of the peak flux distribution in the NG-plane

Plane	i	n_i	ΣR_i	U_i
Area 2 (NG-plane)	2	117	38073	25458
Area 3 (unselected)	3	484	142828	31170

$$t_s = (U_2 - n_2 n_3 / 2) / \sqrt{n_2 n_3 (n_2 + n_3 + 1) / 12} = 1.69$$

Note: $t_{\alpha=0.05} = 1.65$, where t_{α} is the critical value of the t distribution with a significant level α .

4. Discussion and conclusion

Although the spatial distribution of GRBs is isotropic in large-scale, we find some anisotropic signatures in 3B catalog of BATSE. The density of GRBs in the MG-plane and the NG-plane is higher than that in other parts (unselected area) of the sky with significance 2.8 and 1.9σ respectively. The brightness of GRBs in the NG-plane is fainter than that in unselected area with a significant level $\alpha = 0.05$, while no difference is detected between the peak flux distributions in Area 1 (MG-plane) and in Area 3 (unselected area). The distance scale of the MG-plane is $25\text{kpc} < R < 280\text{kpc}$ which is similar to that of the Galactic halo. So it has relatively little effect on the peak

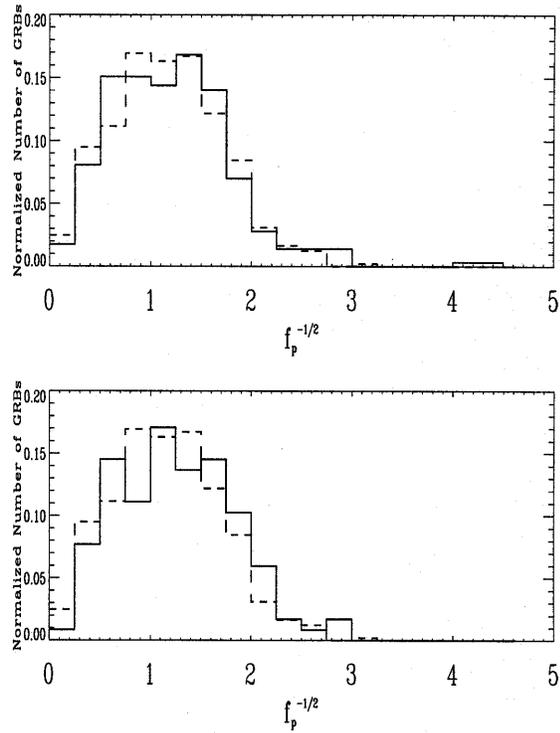


Fig. 5. The peak flux distribution in Area 1 (MG-plane, top) and Area 2 (NG-plane, bottom). f_p is the 1024 ms peak flux. The solid lines show the peak flux distribution in the selected areas. For comparison, the dot lines indicate the distribution of peak flux in the unselected area. All the number of GRBs is normalized.

flux distribution. In the case of the NG-plane, since its distance scale ($1\text{Mpc} < R < 11\text{Mpc}$) is much greater than that of the Galactic halo, it has more effect on the peak flux distribution than the MG-plane and the difference in peak flux distribution is detected. The results suggest that GRBs, or at least a substantial fraction of them may do not originate at cosmological distances. Most GRBs may originate in an extended Galactic halo, some faint ones may originate from nearby galaxies and their extended halos or some unknown objects which are related to the NG-plane.

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