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The Signature of an Anisotropic Distribution of Gamma-ray Bursts† ⋆

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Abstract Anomalies of the cosmic microwave background (CMB) map have been widely acquainted nowadays via the Wilkinson Microwave Anisotropy Probe (WMAP) satellite and the Planck satellite. One anomaly is the alignment of multipole moments from $l = 2$ to $l = 5$. In our work, we investigate the angular distribution of gamma-ray bursts (GRBs) to find whether there exists an anomaly similar to that of CMB. We perform the spherical-harmonic expansion on the GRB sample to derive the coefficients of a few foremost terms. It is found that a rough alignment of multipole moments from $l = 2$ to $l = 4$ exists, while the multipole moment of $l = 5$ points to a different direction. And that the quadrupole moment is obviously of planar distribution, while the other ones are normal.

Key words gamma-ray bursts—cosmology: cosmic background radiation

1. INTRODUCTION

The cosmic microwave background (CMB) is an observational phenomenon that reflects the profound properties of our universe. A decade ago, some anomalies[1] had been discovered by analyzing the CMB data from the Wilkinson Microwave Anisotropy Probe (WMAP). The anomalies include: (1) The quadrupole moment of CMB on its own is anomalous at the 1-in-20 level by being low; (2) The octupole moment of CMB on its own is anomalous at the 1-in-20 level by being very planar; (3) The alignment between the quadrupole moment and the octupole moment is anomalous at the 1-in-60 level. Afterwards, many researchers were

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involved in this field[2−4]. And it was further revealed that the multipole moments of l =1-5 are highly aligned with each other[5]. Recently, a much more precise CMB map from the Planck satellite provided access to a detailed analysis, and further confirmed the anomalies with higher confidence[6−7]. But until now these anomalies remain to be puzzling.

Besides CMB, there are some similar phenomena found in other observations. Through analyzing quasar spectra, the fine structure constant is found to be distributed anisotropically, i.e. there exists a significant dipole moment in the direction of right ascension $(17.5\pm0.9)^h$ and declination $(-58 \pm 9)^{\circ}$[8]. Through analyzing supernovae, there is also a preferred direction of cosmic expansion at $(b, l) \sim (28^{\circ}{}^{-33^{\circ}}_{+11^{\circ}}, 314^{\circ}{}^{-13^{\circ}}_{+20^{\circ}})$[9−10]. In addition, Gamma-ray bursts (GRBs) have been used to constrain the cosmological parameters[11−12].

Inspired by the above intriguing anomalies, we pay attention to GRBs. Contrary to CMB, GRBs are violent and common events in the universe, and the detection rate is a few events per day by some instruments. GRBs are of high redshifts among most observable objects in the universe, thus containing much information about our universe. What we are interested in is the sky distribution of GRBs, which has been studied by some authors[13−18]. It has been found that the short and intermediate GRBs distribute anisotropically, while the long GRBs almost isotropically. Tikhomirova et al.[19] proposed a simple method to derive the quadrupole moment of the GRB distribution, and found that it is extremely small.

In this paper, we use an approach similar to the CMB analysis (spherical-harmonic expansion) to analyze the angular distribution of GRBs, and to obtain the coefficients of the expansion terms, then perform the same procedures as Oliveira-Costa et al.[1] to check whether there are anomalies in the angular distribution of GRBs. Unlike the CMB, the study of angular distribution of GRBs can start from the dipole moment. In Section 2, we introduce an approach to derive the spherical harmonic coefficients, and simulate a group of samples of some specific distribution modes to test the approach. In Section 3, we apply the method in Section 2 to the GRB sample. And the conclusion and discussion are made in Section 4.

2. SPHERICAL-HARMONIC EXPANSION

A continuous function on a spherical surface can be developed with spherical harmonics as follows:

$$f(\theta, \varphi) = \sum_l \sum_m a_{lm} Y_{lm}(\theta, \varphi), \tag{1}$$

where

$$a_{lm} = \int_\theta \int_\varphi f(\theta, \varphi) Y_{lm}(\theta, \varphi)^* \sin\theta \mathrm{d}\theta \mathrm{d}\varphi. \tag{2}$$

The spherical harmonics $Y_{lm}(\theta, \varphi)$ are normalized as

$$\int_\theta \int_\varphi Y_{lm}(\theta, \varphi) Y_{l'm'}(\theta, \varphi)^* \sin\theta \mathrm{d}\theta \mathrm{d}\varphi = \delta_{ll'}\delta_{mm'}. \tag{3}$$