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# Angular distribution analysis of Short Gamma-Ray Burst Fluence from the Fermi catalog

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**Abstract.** The hypothesis of statistical isotropy on large scales, a core aspect of the cosmological principle, asserts that the angular distribution and physical properties of cosmic objects should show no preferred direction. In this work, we test the isotropy of short Gamma-Ray Burst (SGRB) fluences using the latest FERMI/GBM dataset, comprising 614 events. By employing a directional analysis method based on hemispheric scans and constructing the $f^{\rm SGRB}$-map, we calculate the angular power spectrum to quantify directional variations. Results indicate that the fluence distribution of SGRB is statistically isotropic, with multipole moments consistent with isotropy at $1\sigma$ and $2\sigma$ levels when compared to 500 simulated isotropic maps. Notably, the dipolar component dominates the $f^{\rm SGRB}$-map, with its direction in galactic coordinates measured as $(l, b) = (69.70° \pm 22.5°, -57.26° \pm 22.5°)$. While this dipolar nature is not anomalous compared to isotropic simulations, its origin remains unclear, warranting further investigation.

**Resumo.** A hipótese de isotropia estatística em grandes escalas, um aspecto central do princípio cosmológico, afirma que a distribuição angular e as propriedades físicas dos objetos cósmicos não devem mostrar nenhuma direção preferencial. Neste trabalho, testamos a isotropia de fluências curtas de Gamma-Ray Burst (short Gamma-Ray Burst; SGRB) usando o mais recente conjunto de dados FERMI/GBM, compreendendo 614 eventos. Empregando um método de análise direcional baseado em varreduras hemisféricas e construindo o mapa $f^{\rm SGRB}$, calculamos o espectro de potência angular para quantificar variações direcionais. Os resultados indicam que a distribuição de fluência dos SGRB é estatisticamente isotrópica, com momentos multipolares consistentes com isotropia nos níveis $1\sigma$ e $2\sigma$ quando comparados a 500 mapas isotrópicos simulados. Em particular, o componente dipolar domina o mapa $f^{\rm SGRB}$, com sua direção em coordenadas galácticas medidas como $(l, b) = (69.70° \pm 22.5°, -57.26° \pm 22.5°)$. Embora essa natureza dipolar não seja anômala em comparação com as simulações isotrópicas, sua origem é desconhecida, justificando uma investigação mais aprofundada.

**Keywords.** Cosmology: observations – large-scale structure of Universe – Gamma rays: galaxies

## 1. Introduction

One of the fundamental hypotheses in cosmology is that the universe is statistically isotropic on large scales, which forms a core aspect of the cosmological principle (CP) (Bernui et al., 2006, 2009; Novaes et al., 2016; Aluri et al., 2017; Bernui et al., 2018; Marques et al., 2018; Avila et al., 2019; Kester et al., 2024; Awwad & Prokopec, 2024; Franco et al., 2024a). This principle states that the angular distribution and other physical properties of a given ensemble of cosmic objects should exhibit no preferred direction.

Studies of statistical isotropy, and statistical homogeneity, using various cosmic probes and methodologies, are important because they help to verify the universality of the cosmological principle, but could also provide insights into the astrophysical properties of the sources, or even give indications of the presence of systematics (see, e.g., Bernui et al. (2007, 2008); Javanmardi et al. (2015); Tiwari & Jain (2019)).

GRB are high-energy electromagnetic events in the universe, associated with different physical mechanisms. Classically, GRB were classified into two populations based on their duration in the $\gamma$-ray band (Kouveliotou et al., 1993): short ($T_{90} \lesssim 2$ s)[1] and long ($T_{90} > 2$ s) duration GRB. The short bursts are associated with the merging of two relativistic compact objects, while long bursts are associated with the core collapse of massive stars (Vedrenne & Atteia, 2009).

Over the last few decades, the angular distribution of GRB in the sky has been the subject of analysis (Bernui et al., 2008; Gibelyou & Huterer, 2012; Tarnopolski, 2017). However, few studies have examined the angular distribution of the physical properties of GRB. In recent studies, Lopes et al. (2024b) found a fluence distribution consistent with the isotropy of GRB, both in the FERMI GRB catalog (von Kienlin et al., 2024) and in subsamples of short and long GRB, using a directional analysis with hemispheres. On the other hand, Ripa & Shafieloo (2017, 2019) analyzed the properties of GRB, such as their duration, fluences and peak fluxes in various energy ranges and different time scales, also finding consistency with isotropy for different tests.

In this work, we analyze the most recent FERMI/GBM dataset[2] to investigate the angular distribution of the Short Gamma-Ray Burst fluence across the celestial sphere. The details of the FERMI/GBM data are outlined in Section 2, while the methodology for directional analysis using hemispheres is described in Section 3.1. Our results and conclusions are presented in Sections 4 and 5, respectively.

## 2. Observational data: The Fermi GMB Catalog

The sample of Gamma-Ray Bursts from the Fermi GBM Burst Catalog contains 3703 events (updated February 2024), shown in Figure 1 in Lopes et al. (2024a). For our analysis, we selected

[1] Where $T_{90}$ is the timescale during which 5% to 95% of the counts are accumulated.

[2] https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

short gamma-ray bursts based on the criterion $T_{90} \lesssim 2$ s, ensuring that all events had fluence measurements available. Thus, our final sample consists of 614 Short GRB, which we shall call the SGRB sample, along with angular position data and fluence measurements for all events in the nominal energy band interval of 10-1000 keV. The angular distribution of SGRB in the full sky can be seen in Figure 1, where the color bar represents the fluence measure corresponding to each event.

Therefore, in our analysis, we will use the following observable quantities in the SGRB sample from the catalog: fluence (erg/cm$^2$), in the catalog denoted as *fluence* and galactic coordinates $l\,(°)$ and $b\,(°)$ in the catalog denoted as *lii* and *bii*, respectively.

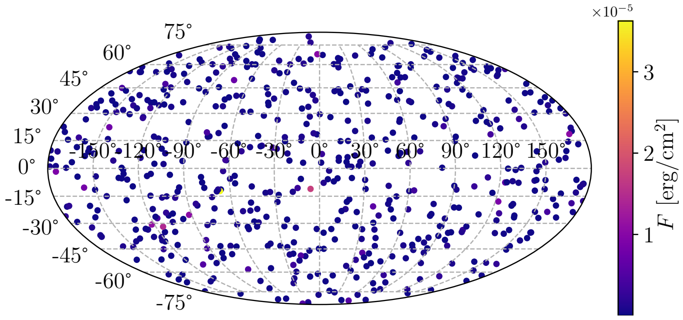


**Figure 1.** The mollweide projection of the set of 614 SGRB, in galactic coordinates, and the bar colored with the fluence measurement.

## 3. Methodology

To quantify the directional variation of the fluence of the GRB sample, we apply a coordinates-free method using spherical caps (Bernui et al., 2008; Kester et al., 2024) with a 90° radius, which corresponds to a hemisphere.

### 3.1. Directional analysis: the $f^{\rm SGRB}$-map

We performed our directional analysis by scanning the celestial sphere in 192 hemispheres using the pixelization algorithm from the Healpy/HEALPix library with $N_{side} = 4$.

We'll consider the GRB in the $i$-th hemisphere, with center in $(\theta_i, \phi_i)$, and define a scalar function to associate a non negative real value, that is

$$\overline{\rm F}_i : \Omega^i_\gamma \subset \mathcal{S}^2 \longrightarrow \mathbb{R}^+ \,, \quad (1)$$

for each i from 1 to $N_{hemis}$, the fluence $\overline{\rm F}$ is defined as the median value of the fluences of the set of fluences of the GRB located in the $i$-th hemisphere.

The set of $N_{hemis}$ values, $\{\overline{\rm F}_i\}$, para $i = 1, ..., N_{hemis}$, are then assembled into a colored complete sky map, the $f^{SGRB}$-map. This generated map can be decomposed into spherical harmonics, allowing the calculation of its angular power spectrum

$$\mathcal{F}_\ell \equiv \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a^{\overline{\rm F}}_{\ell m}|^2 \,, \quad (2)$$

where $\ell$ is the multipole moment and $a_{\ell m}$ are the spherical harmonic coefficients, for the multipoles $\ell = 0, 1, 2, \ldots$, where the value of $\ell_{\rm max}$ depends on the resolution of the map.

### 3.2. Simulating isotropic fluence maps: $f^{\rm ISO}$-maps

An essential aspect of our directional analysis involves comparing our spectral results with those obtained by applying the same methodology to generate $f^{\rm ISO}$-maps, under the assumption of statistical isotropy (SI).

For this aim, we randomize the original dataset obtaining $F_i^{ran}$, then each of these values is changed by a value randomly selected from a gaussian distribution with mean $F_i^{ran}$ and standard deviation equal to its measured uncertainty $\sigma F_i^{ran}$, obtaining $F_i^{ran+gau}$. The set of triplets $(\alpha_i, \delta_i, F_i^{ran})$ , $i = 1, ..., 614$, form one simulated catalog, generated under the SI hypothesis, that after applying our directional analysis procedure produces one $f^{\rm ISO}$-map. We repeat this procedure to finally obtain 500 $f^{\rm ISO}$-maps.

## 4. Results

The large-scale evolution of matter structures in the universe, from primordial density fluctuations to the large and huge matter structures observed today, is the objective of several current analyses (de Carvalho et al., 2018, 2020; Marques & Bernui, 2020; Avila et al., 2021, 2022a,b; Franco et al., 2024b; Sorrenti, Durrer, & Kunz, 2024a,b). The GRB are high-energy electromagnetic events in the universe, associated with different physical mechanisms, and the question is if they happen everywhere and with similar properties (Mehta & Iyyani, 2024; Lopes et al., 2024b).

According to the methodology described in section 3.1, we calculated the $f^{\rm SGRB}$-map by scanning the celestial sphere with 192 hemispheres. The next step was to calculate the corresponding angular power spectra. Our results are shown in Figure 3, where we see the angular power spectrum for the $f^{\rm SGRB}$-map, from which the spectrum has been calculated for $\ell = 1, \ldots, 5$. The $f^{\rm SGRB}$-map and its dipolar component are displayed in Figure 2. The dipolar component is clearly the dominant multipole component.

To analyze the statistical significance of the multipole components of the $f^{\rm SGRB}$-map, we compare it with the 500 simulated SI $f^{\rm ISO}$-maps. To do this, we calculate the angular power spectrum of the $f^{\rm ISO}$-maps and determined their median, which can be seen in Figure 3, along with the $1\sigma$ and $2\sigma$ regions in gray colors. Although the dipolar behavior is evident in the $f^{\rm SGRB}$-map, it is not anomalous when compared to the set of corresponding isotropic maps. In Figure 3 we observe that the $f^{\rm SGRB}$-map is consistent with statistical isotropy at $\sim 1\,\sigma$ confidence level.

We also calculate the direction of the dipole, in galactic coordinates, finding $(l, b) = (69.70° \pm 22.5°, -57.26° \pm 22.5°)$. In Lopes et al. (2024a), the authors found the directions for the fluence dipole for other GRB data sets, also consistent with isotropy, but none of these directions is close with the one found in the present work. The explanation of the dipolar nature of the $f^{\rm SGRB}$-map found in this analysis is unknown and deserves further study.

## 5. Conclusions

In this work, we investigated the angular distribution of fluence in Short Gamma-Ray Bursts (SGRB) using the latest FERMI/GBM dataset. Our analysis demonstrated that the observed distribution is statistically consistent with isotropy, as supported by comparisons with simulated isotropic maps.

A notable feature in our results is the strong dominance of the dipolar component in the $f^{\rm SGRB}$-map, evident in both the

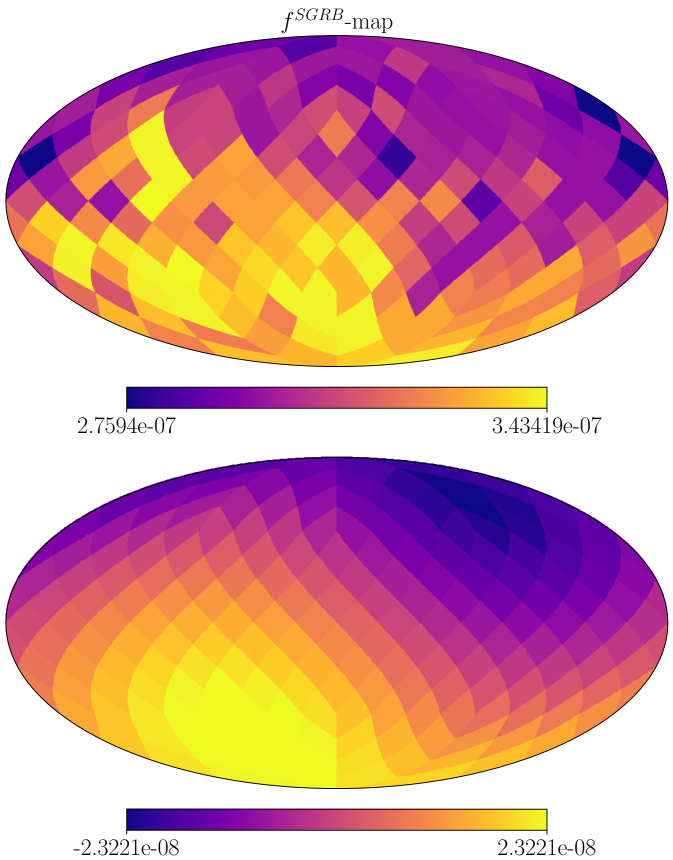


**Figure 2.** The $f^{\rm SGRB}$-map in the top panel, where the bar is colored according to the median fluence intensity in units of erg/cm$^2$ and the dipole map in the bottom panel.

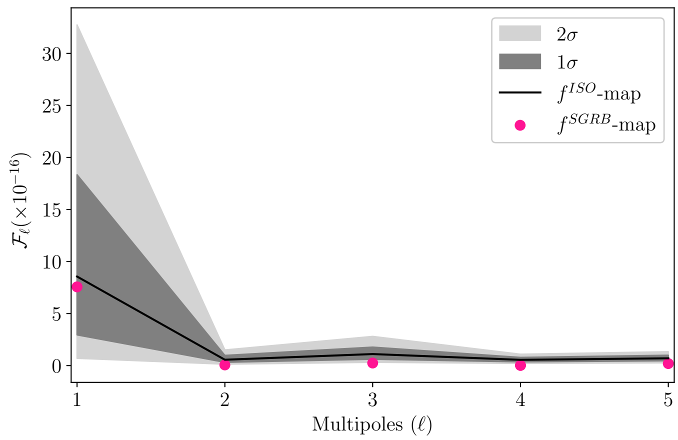


**Figure 3.** The angular power spectrum of the $f^{\rm SGRB}$-map shows that the dipole is the dominant multipole component.

map itself and its angular power spectrum. While this dipole behavior falls within the expected variance under the assumption of isotropy, its prominence is intriguing and warrants further investigation. The direction of the dipole, determined as $(l, b) = (69.70^\circ \pm 22.5^\circ, -57.26^\circ \pm 22.5^\circ)$, differs from previously reported fluence dipole directions, including those in Lopes et al. (2024b), suggesting possible sample-dependent effects or methodological sensitivities.

These findings highlight the need for additional studies to understand the origin and nature of the observed dipolar feature. Future analyses could explore alternative directional methods, assess systematic uncertainties in fluence measurements, and investigate potential correlations with large-scale cosmic structures or observational biases.

Our study reinforces the suitability for directional analyses in testing the statistical isotropy of the universe and contributes to the broader understanding of GRB properties as powerful cosmic probes of modern cosmology.

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