Testing Isotropic Universe via Properties of Gamma-Ray Bursts Detected by *Fermi*/GBM

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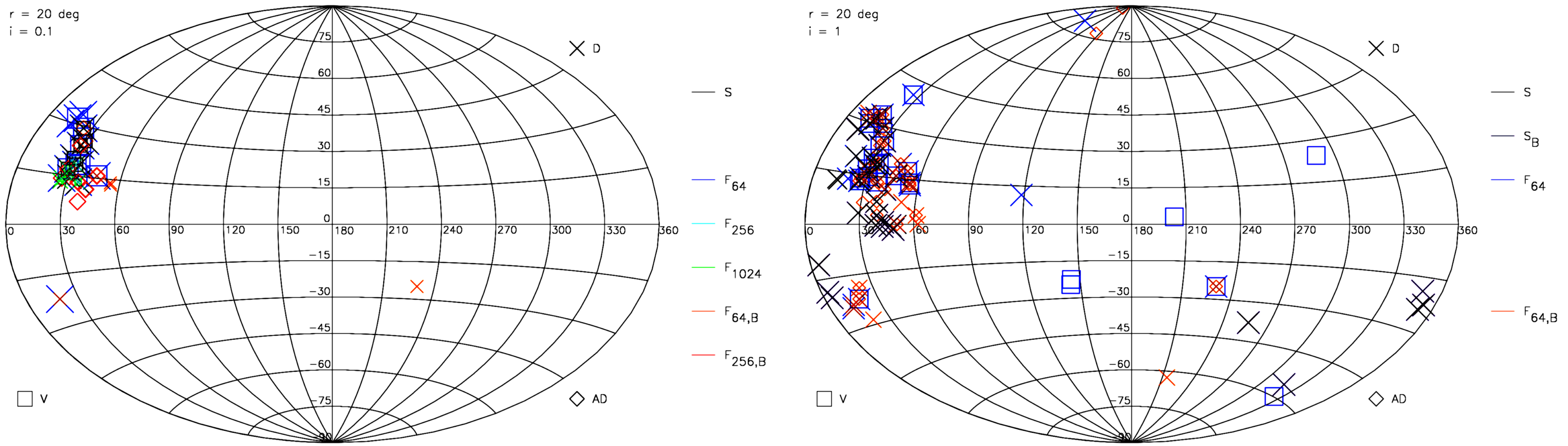
Abstract

The sky distribution of Gamma-Ray Bursts (GRBs) has been intensively studied for more than two decades. Most of these studies, test the isotropy of GRBs based on the sky number density distribution. **We propose a new method which inspects the isotropy of the properties of GRBs** such as their duration, fluences and peak fluxes at various energy bands and different time scales. The method was applied on the ***Fermi*/Gamma-ray Burst Monitor** data. **We found a relatively significant feature near the Galactic coordinates approximately $\mathbf{l = 30\,deg}$, $\mathbf{b = 15\,deg}$ and radius $\mathbf{r = 20 - 40\,deg}$** with the inferred probability for the occurrence of such signal (in a random isotropic sample) to be less than a percent. However, more comprehensive analysis using different statistical tests and different samples show that the detected **feature can be due to statistical fluctuations**. Investigations on the **updated *Fermi*/GBM sample** as well as on the **data sets of other instruments can clarify on the issue**.

Results (details are in arXiv:1706.03556)



Example of our results. Plotted are the patch centers (Galactic Coordinates), for which the statistical properties of GRBs are mostly deviated from randomness. That is the patches for which a given statistic ξ^m, for the measured data, is higher than a limiting value ξ_i^s and the significance $P_i^N \leq 5\,\%$. The used test statistics are $\xi = \chi^2$ (two-sample Chi square), D (Kolmogorov-Smirnov), V (Kuiper), or AD (Anderson-Darling).

Introduction

Various observations claimed existence of **large-scale structures** in the Universe of sizes of **several hundreds of Mpc or even beyond 1 Gpc**, e.g.: **Sloan Great Wall** of galaxies $\sim 420\,\mathrm{Mpc}$ (Gott et al. 2005); **VLA Sky Survey** suggested a 140 Mpc empty void (Rudnick et al. 2007); **Huge Large Quasar Group** of longest dimension $\sim 1.2\,\mathrm{Gpc}$ at mean $z = 1.27$ (Clowes et al. 2013).

Concerning **Gamma-Ray Bursts (GRBs) initially they had been claimed to be distributed isotropically on the sky** (Meegan et al. 1992; Briggs et al. 1996). **Later works indicated that their sky distribution may have some level of anisotropy** (Balázs et al. 1998, 1999; Mészáros et al. 2000a,b; Magliocchetti et al. 2003; Mészáros & Štoček (2003); Vavrek et al. 2008; Veres et al. 2010; Tarnopolski 2015). Recently, Horváth et al. (2014) and Horváth et al. (2015) claimed that there is a significant clustering of GRBs at redshift $1.6 < z \leq 2.1$ and size $\sim 2.0 - 3.0\,\mathrm{Gpc}$, so called **"Hercules-Corona Borealis Great Wall"**. However, Ukwatta & Wozniak (2016) claimed that their analysis did not provide evidence of such significant clustering. Recently, Balázs et al. (2015) reported **a giant ring-like clustering** with a diameter of 1.7 Gpc, displayed by 9 GRBs at redshift $z \sim 0.8$. **All these GRB studies test the isotropy using the distribution of the number density. In work Řípa & Shafieloo (2017) (arXiv:1706.03556) we proposed an approach to test the isotropy of the Universe through inspecting the isotropy of the properties of GRBs.**

Data Sample

We employed data from the Gamma-ray Burst Monitor (GBM) (Meegan et al. 2009) of the *Fermi* satellite (Atwood & GLAST Collaboration 1994). Specifically we utilized the **Fermi GBM Burst Catalog (FERMIGBRST[1])** (Gruber et al. 2014; von Kienlin et al. 2014; Narayana Bhat et al. 2016). A sample containing 1591 GRBs with following observables is used:

- **GRB position** in Galactic coordinates **l, b** (deg).
- **Duration $\mathbf{T_{90}}$** (s) in range $(50 - 300)$ keV.
- **Peak fluxes $\mathbf{F_{64}}$, $\mathbf{F_{256}}$** and **$\mathbf{F_{1024}}$** ($\mathrm{ph\,cm^{-2}\,s^{-1}}$) at 64-ms, 256-ms, 1024-ms timescales and in energy range $(10 - 1000)$ keV.
- **Peak fluxes $\mathbf{F_{64,B}}$, $\mathbf{F_{256,B}}$** and **$\mathbf{F_{1024,B}}$** ($\mathrm{ph\,cm^{-2}\,s^{-1}}$) at 64-ms, 256-ms, 1024-ms timescales and in the BATSE standard energy band $(50 - 300)$ keV.
- **Fluence S** ($\mathrm{erg\,cm^{-2}}$) in the energy range $(10 - 1000)$ keV.
- **Fluence $\mathbf{S_B}$** ($\mathrm{erg\,cm^{-2}}$) in the BATSE standard energy band $(50 - 300)$ keV.

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

Method

We **compare distributions of a given measured GRB property** (e.g. duration or flux) for a large number of randomly spread **patches on the sky** with a distribution of the same GRB property for **the whole sky**. We use **several test statistics** to give us the measure of the differences between the distribution for a random patch and the whole sky. Then we **compare** the obtained distributions of the test statistics derived from the **measured data** with the distributions of the test statistics for **randomly shuffled data** to infer the significance of potential anisotropies.

1. Generate **1000 randomly placed patches** of radius r on sky.
2. For **each patch** and the **whole sky** compare the distributions of the given GRB property by calculating several test statistics $\boldsymbol{\xi} =$ $\boldsymbol{\chi^2}$ **(two-sample Chi square), D (Kolmogorov-Smirnov), V (Kuiper), or AD (Anderson-Darling)**.
3. This gives, **for each test statistic, a distribution of 1000 values of $\boldsymbol{\xi^{\mathrm{m}}}$** (index **m marks measured data**).
4. Next we **randomly shuffle** the measured data sample (100x). We keep the coordinates l_i , b_i of each measurement and we randomly shuffle the values of the measured GRB properties.

Method

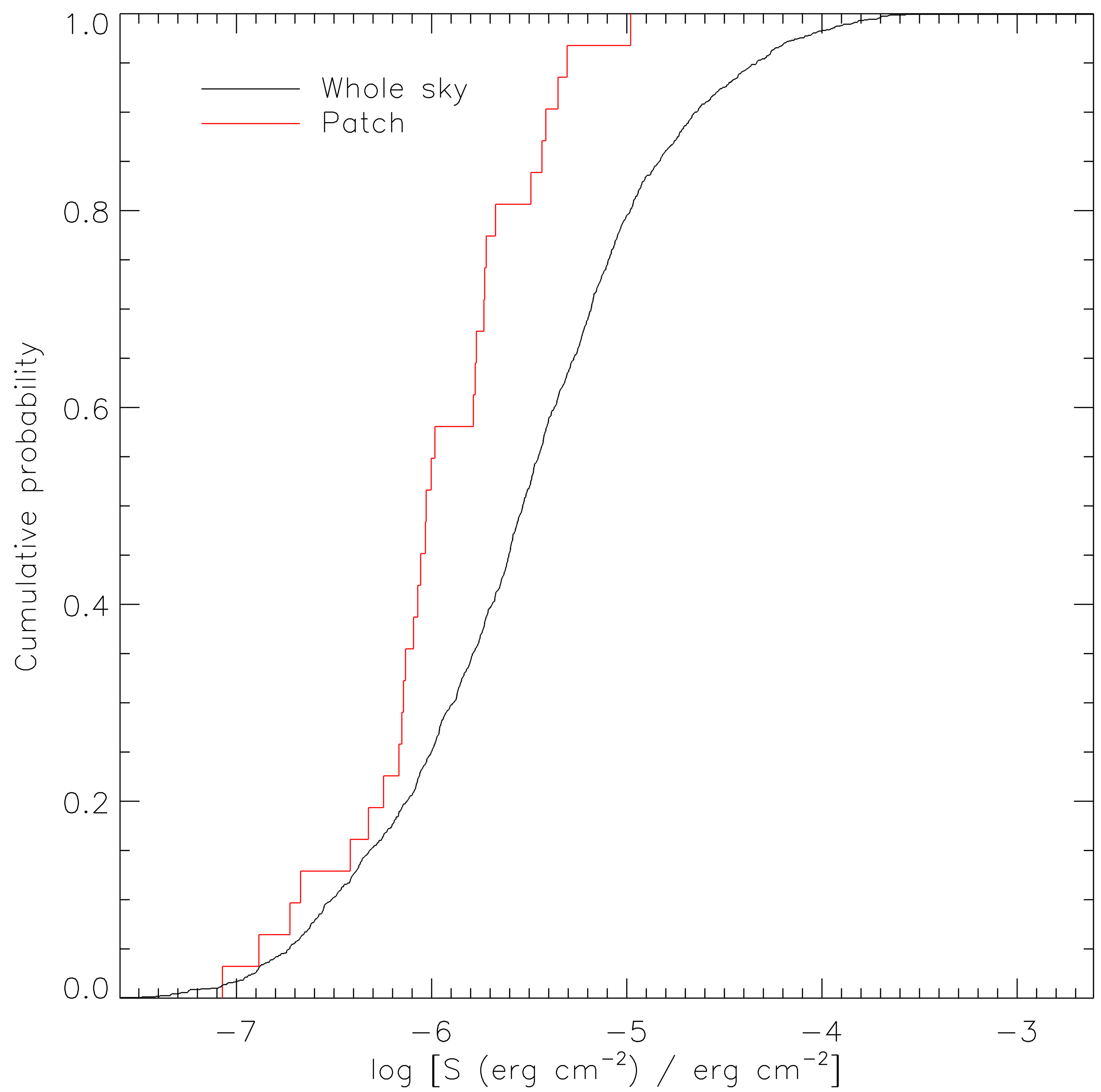
5. For **each patch** and the **whole sky compare** the distributions of the given GRB property in the **shuffled data by calculating the test statistics** $\boldsymbol{\xi}$.

6. This gives, **for each test statistic** and **each sky patch**, a **distribution of 100 values of** $\boldsymbol{\xi^s}$ (index **s marks shuffled data**).

7. For a given statistic $\boldsymbol{\xi}$ we derive the **limiting values** $\boldsymbol{\xi^s_i}$ which delimit the highest i=10, 5, 1, 0.1 % of all $\boldsymbol{\xi^s}$ **values from all patches in all randomly shuffled data**.

8. Count the **number of patches** $\boldsymbol{N^m_i}$ **in the measured data for which** $\boldsymbol{\xi^m > \xi^s_i}$.

9. The **mean number of patches** $\boldsymbol{\overline{N^s_i}}$ **in the randomly shuffled data for which** $\boldsymbol{\xi^s > \xi^s_i}$ is $\overline{N^s_i} = 100, 50, 10$, and 1 for i = 10, 5, 1, and 0.1.



Example of step 2) of our method for fluence S and one example patch.

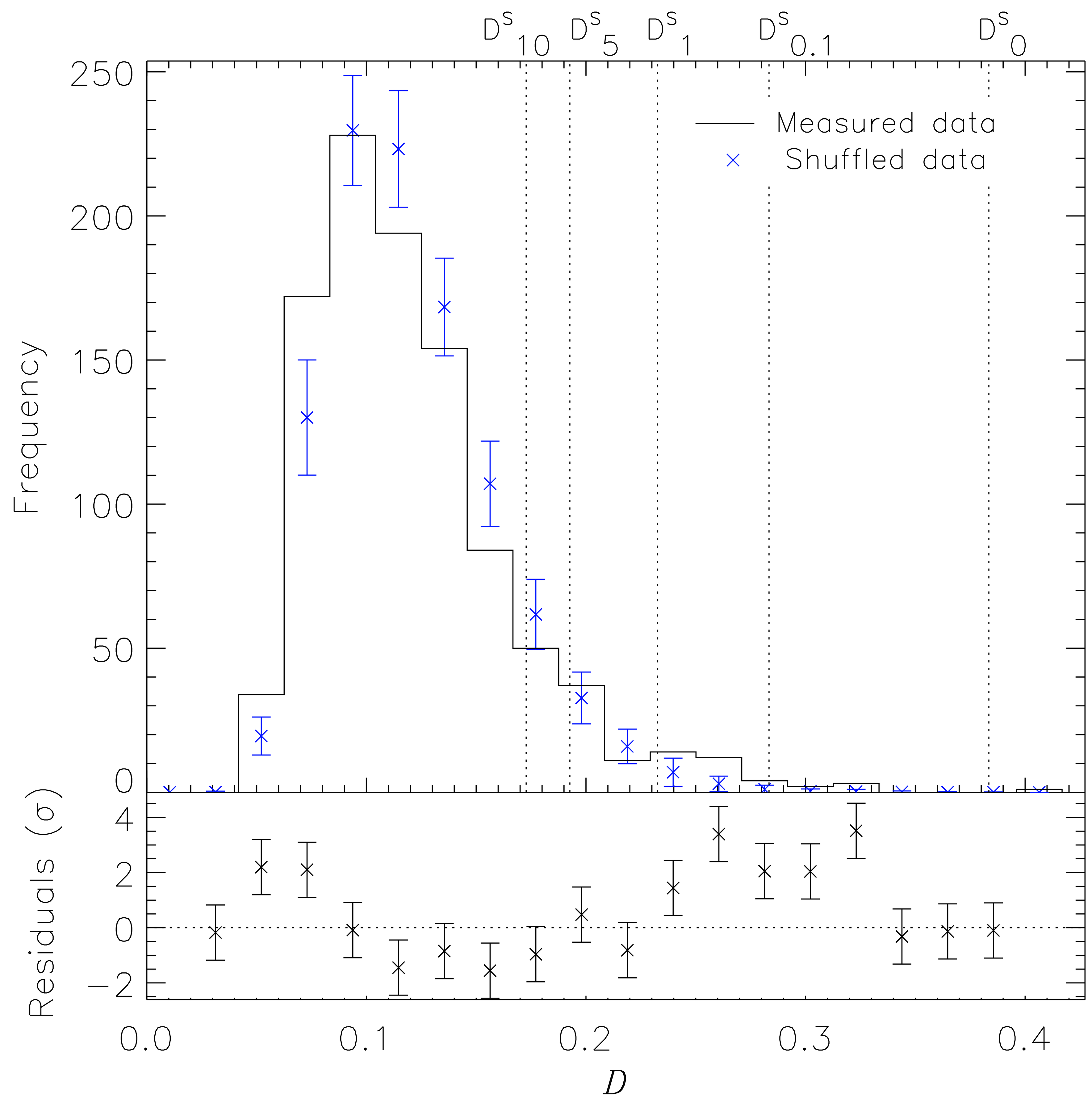
Method

10. If we find $\boldsymbol{N^m_i \gg \overline{N^s_i}}$ for a given i, it **could indicate anisotropy** in the measured data.

11. Next we **calculate the probability** $\boldsymbol{P^N_i}$ **of finding at least** $\boldsymbol{N^m_i}$ **number of patches with** $\boldsymbol{\xi^s > \xi^s_i}$ in the randomly shuffled data.

12. Perform all steps for various patch radii $r = 20°, 30°, 40°, 50°, 60°$, for all GRB properties in our sample and for several test statistics $\boldsymbol{\xi = \chi^2, D, V}$, or $\boldsymbol{AD}$.

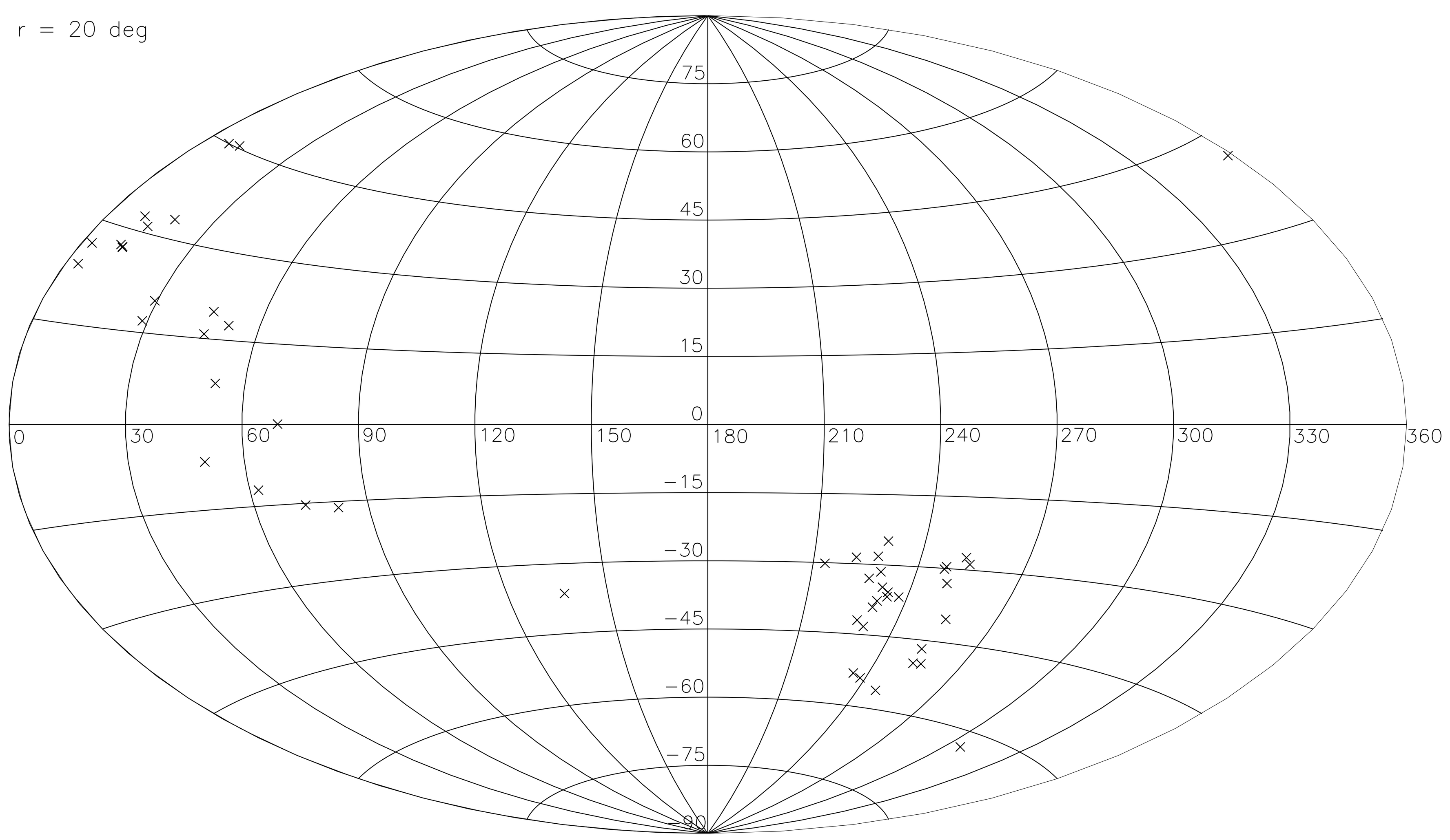
13. For some observables and patch radii where we obtained $P^N_i \leq 5\,\%$ we repeated the whole process with more data shufflings (1000x).



Example of step 8) of our method for fluence S, $r = 20°$, $\xi = D$.

Discussion

A demonstration of our results are shown on the first slide. **The area, where we found a feature, correlates with the less populated area on the sky.** One can expect that the area of reduced GRB density will have relatively larger fluctuations in the measured GRB properties due to the Poisson noise.



Plotted are centers of the 5 % fraction of the lowest occupied patches for radius $r = 20°$.

Conclusions

- We proposed a **new method to test the isotropy of the Universe by testing the observed properties of GRBs** from large datasets.
- We applied the method on the ***Fermi*/GBM data sample** with 1591 GRBs.
- We found a **feature near the Galactic coordinates** $\mathbf{l \approx 30°}$, $\mathbf{b \approx 17°}$ **and radius** $\mathbf{r \approx 20° - 40°}$.
- The inferred **chance probabilities** of observing the obtained excess (compared to the randomly shuffled data) of the sky patches with high values of the test statistics went **below 5 %** depending on the tested quantity and the test statistic used. However, many tests gave results consistent with isotropy.

Conclusions

- Moreover, we noticed a **considerably low number of GRBs in this particular patch** which might be due to some instrumentation or observational effects that can consequently affect our statistics. Therefore **likely our results do not point to a significant anisotropy**.
- Further investigation using a **larger *Fermi*/GBM data sample as well as and data samples of other GRB missions is being carried out** in order to confirm or reject this result.

References & Acknowledgements

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