Testing Isotropic Universe Using the Gamma-Ray Burst Data and Discussion of GRB Classes

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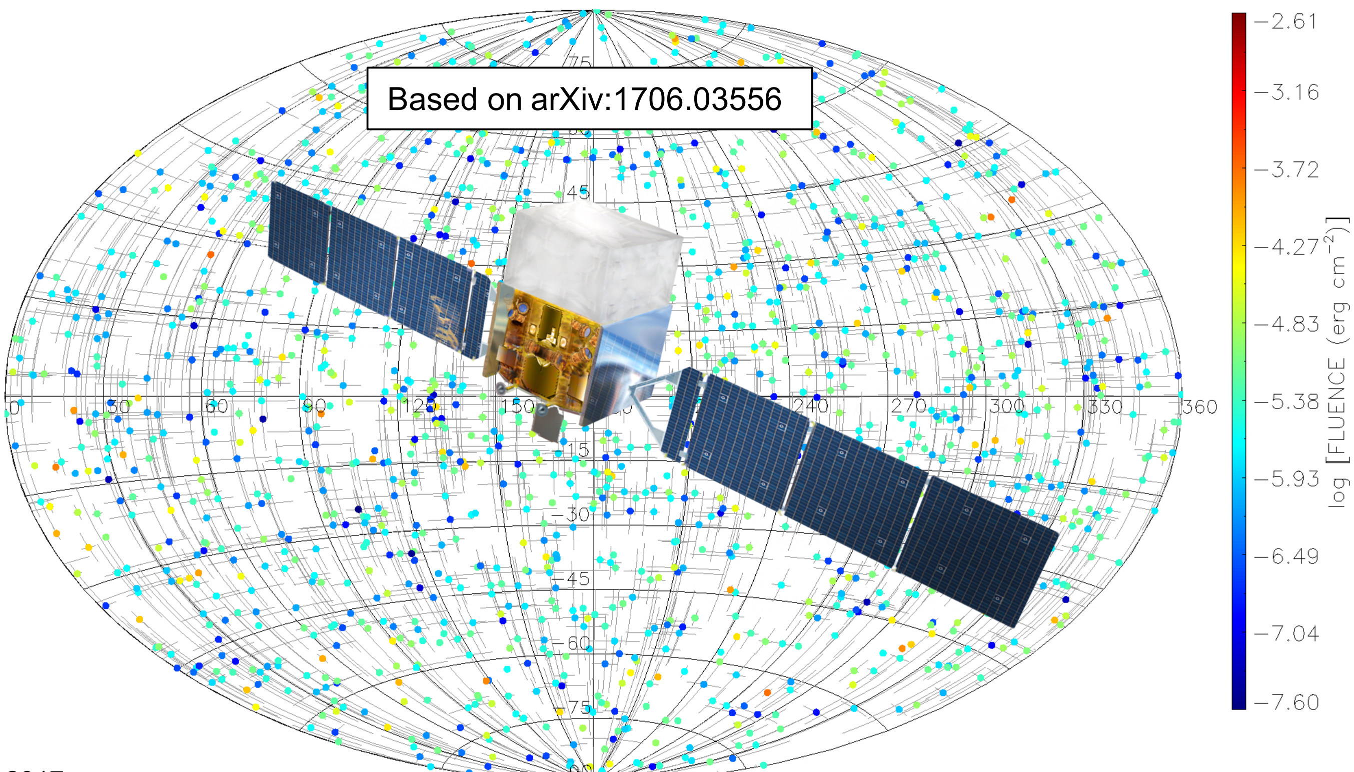
Based on arXiv:1706.03556



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Introduction

- Various observations claimed the existence of large-scale structures in the Universe of sizes of several hundreds of Mpc or even beyond one Gpc, for example:
- Sloan Great Wall of galaxies ~ 420 Mpc (Gott et al. 2005).
- VLA Sky Survey suggested a 140 Mpc empty void (Rudnick et al. 2007).
- Huge Large Quasar Group: longest dimension ~1.2 Gpc at mean $\bar{z} = 1.27$ (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 signicant clustering of GRBs at redshift $1.6 < z \leq 2.1$ and size ~ 2.0 - 3.0 Gpc: "Hercules-Corona Borealis Great Wall".
- However, Ukwatta & Wozniak (2016) claimed that their analysis did not provide evidence of such signicant 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 ~ 0.8.
- All these GRB studies test the isotropy using the distribution of the number density.

Data Sample

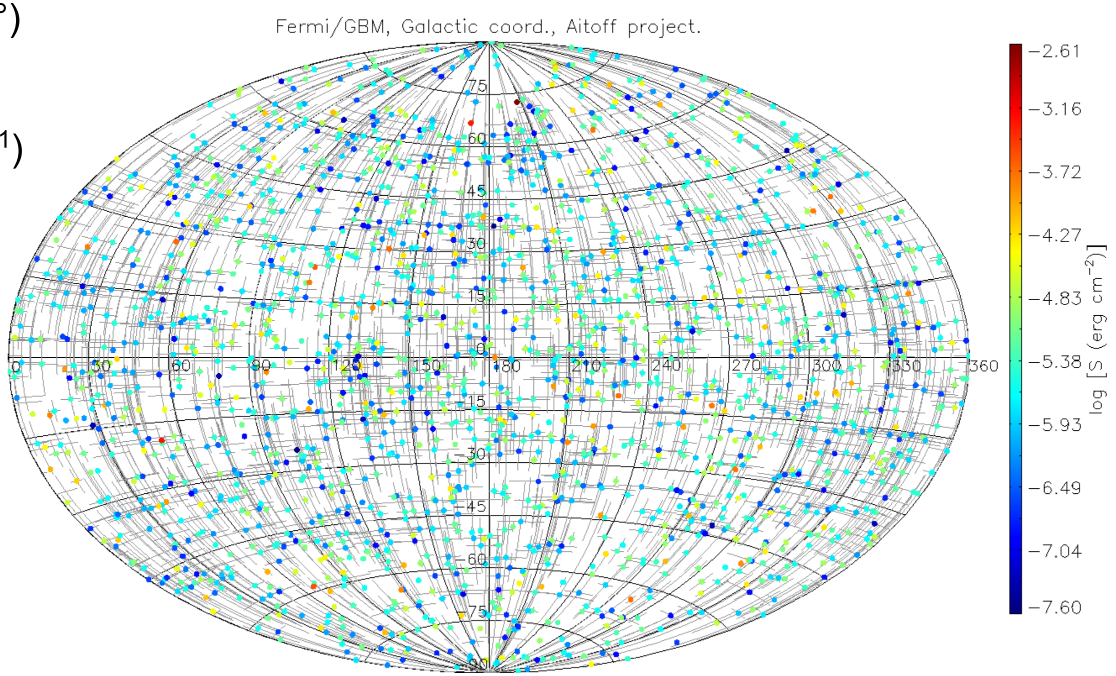
- We propose an approach to test the isotropy of the Universe through inspecting the isotropy of the properties of GRBs **arXiv:1706.03556**.

- We used data from the **Gamma-ray Burst Monitor (GBM)** (Meegan et al. 2009) of the **Fermi satellite** (Atwood & GLAST Collaboration 1994).

- Specifically we used the **Fermi GBM Burst Catalog (FERMIGBRST)** (Gruber et al. 2014, von Kienlin et al. 2014, Narayana Bhat et al. 2016).

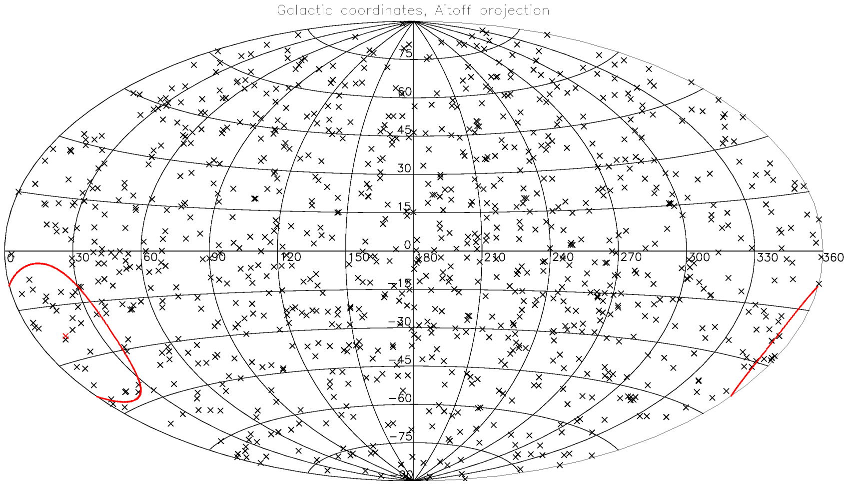
- A sample containing **1591 GRBs** with following observables is used:

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



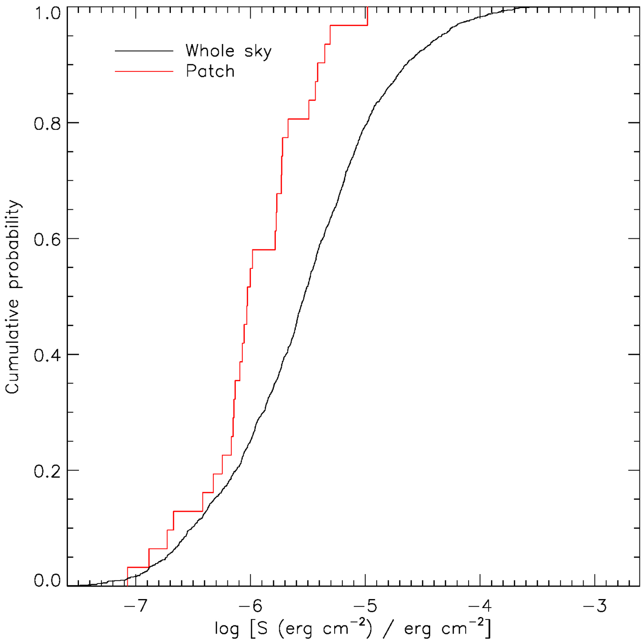
Method

1) Generate **1000 patches** of a radius r **randomly distributed** on the sky.



Red curve is boundary of a random example patch.

2) For **each patch** and the **whole sky** compare the distributions of the given GRB property by calculating several test statistics **ξ = D (Kolmogorov-Smirnov), V (Kuiper)**, **AD (Anderson-Darling)**, or χ^2 **(two-sample Chi square)**.



Method

3) This gives, **for each test statistic**, a **distribution of 1000 values of ξ^m** (index m = **measured data**).

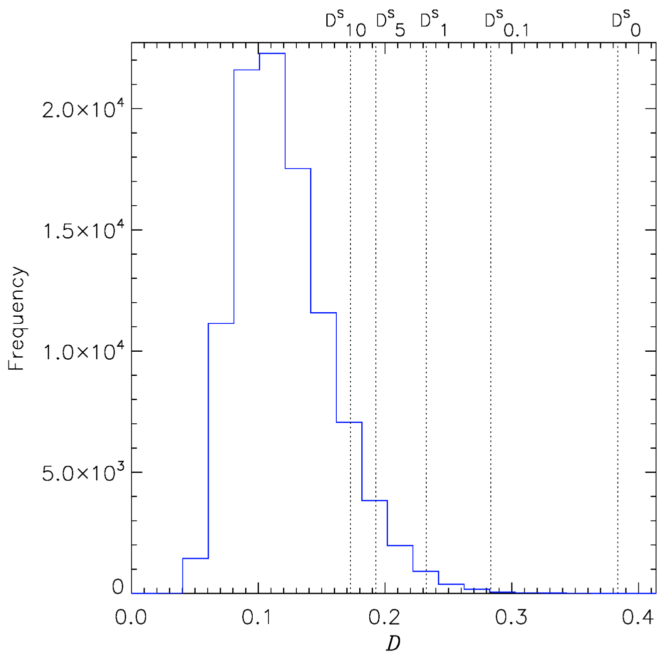
4) Next we **randomly shuffle** the measured data sample (100x). We keep the coordinates l_i , b_i of each measurement and we randomly shuffle the values of the measured GRB properties.

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 **ξ**.

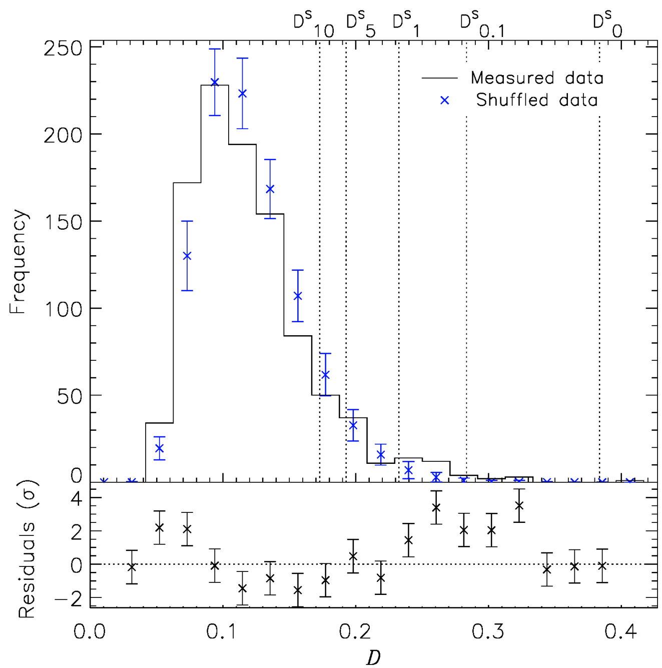
6) This gives, **for each test statistic** and **each sky patch**, a **distribution of 100 values of ξ^s** (index s = **shuffled data**).

7) For a given statistic **ξ** we derive the **limiting values ξ^s_i** which delimit the highest i=10, 5, 1, 0.1 % of all **ξ^s** values f**rom all patches in all randomly shuffled data**.

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



Example for fluence S, r = 20°, ξ = D.



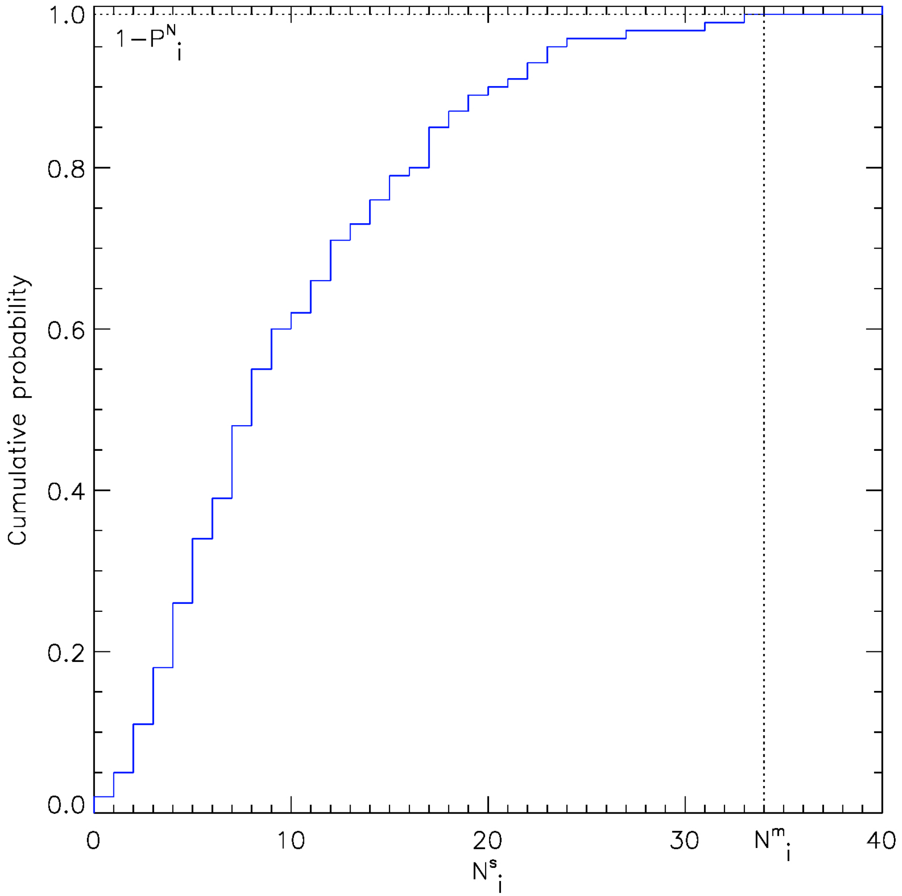
Example for fluence S, r = 20°, ξ = D.

Method

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

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

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



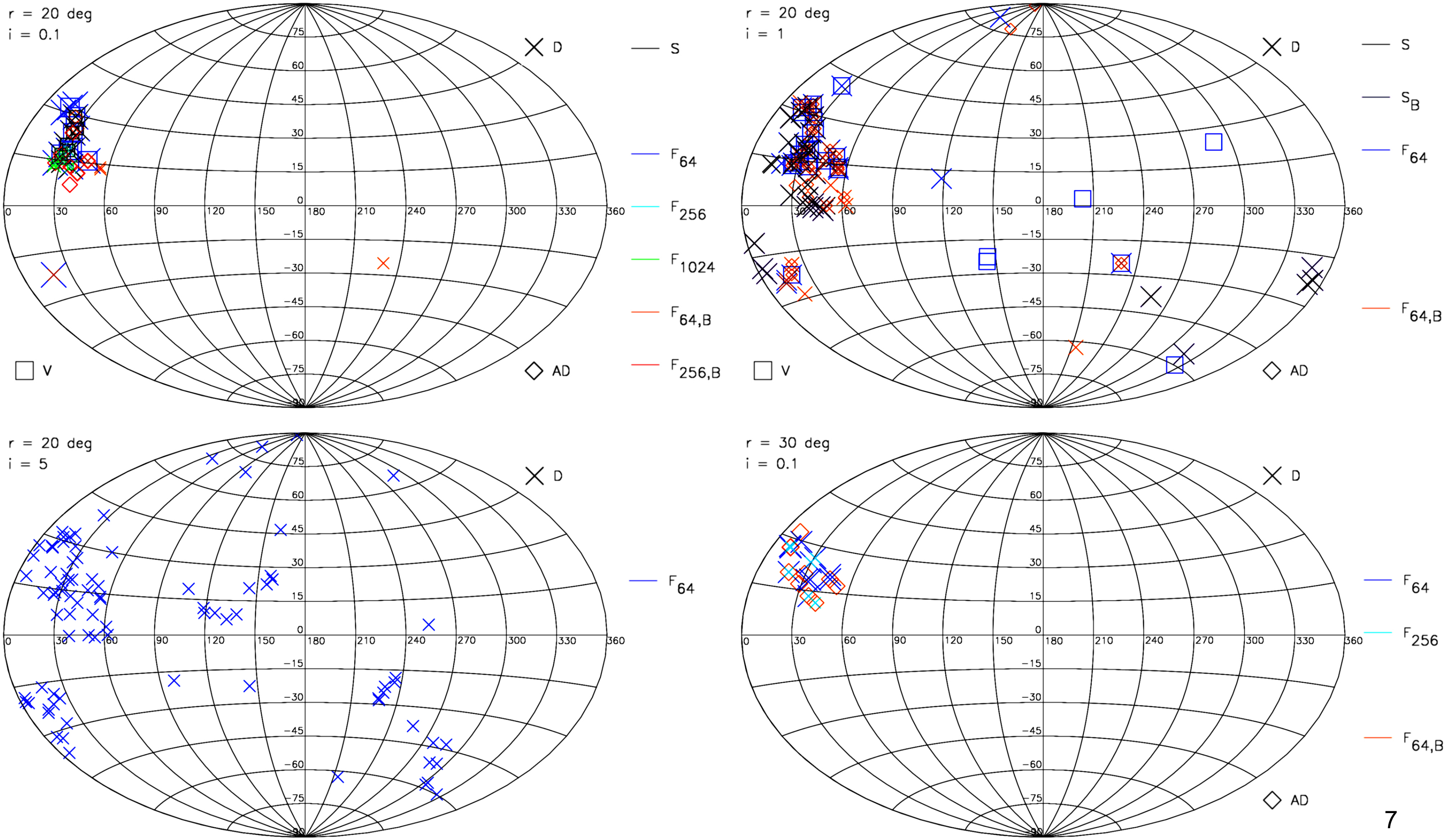
An example of the cumulative distribution of N^s_i for r = 20°, ξ = D, i=1 and 100 data shufflings.

12) Perform all steps for various patch radii r = 20°, 30°, 40°, 50°, 60°, for all GRB properties in our sample and for all test statistics **ξ = D, V, AD,** or χ^2.

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

Results

- Plotted are the patch centers (Galactic Coordinates), for which the statistical properties of GRBs are mostly deviated from the randomness. That is the patches for which a given statistic ξ^m, for the measured data, is higher than ξ^s_i and the significance $P^N_i \leq 5$ %.



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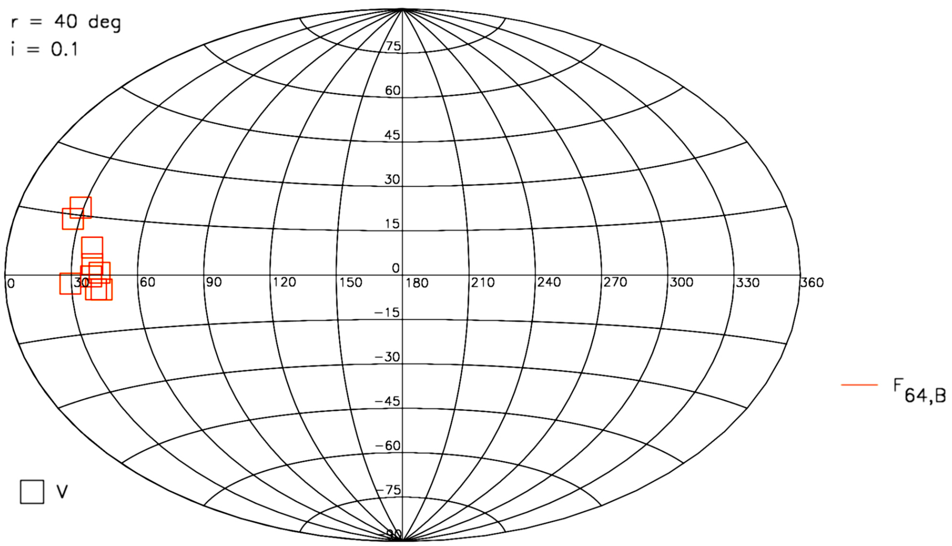
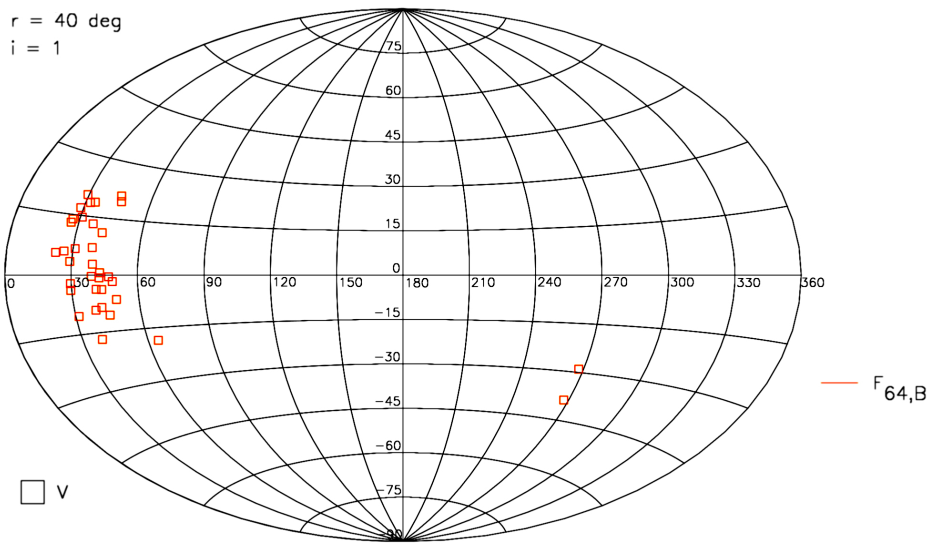
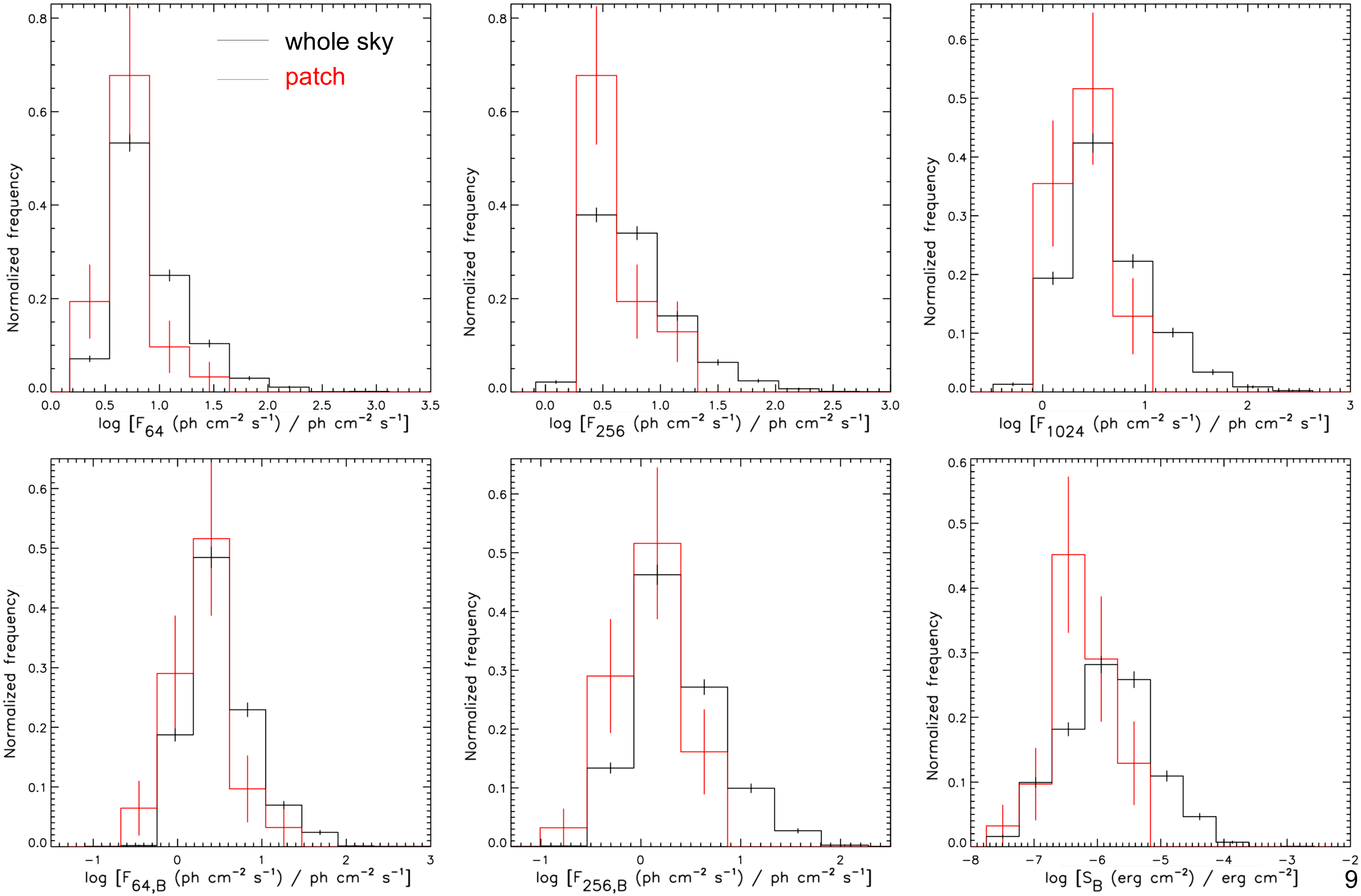




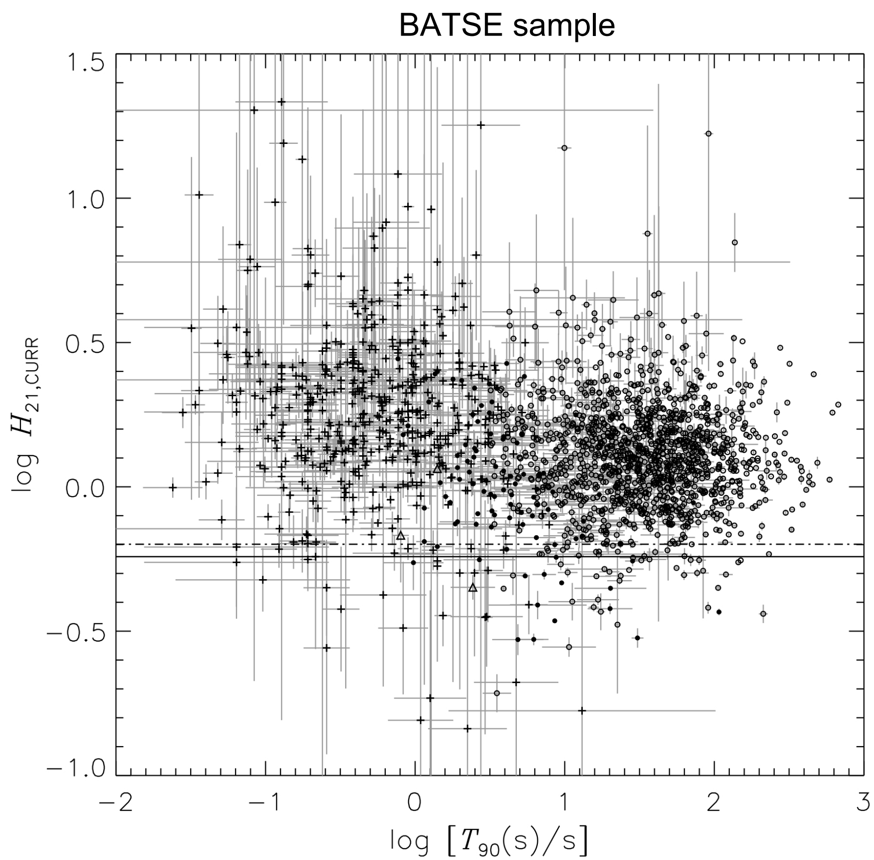
Results

- The distributions of the peak fuxes and fuence obtained for the whole sky and for the patch at the center l = 28.6°, b = 16.9° and radius r = 20°.



Future prospect - testing isotropy for separate GRB groups

- In work by **Řípa & Mészáros 2016, Ap&SS, 361, 370** relation of GRBs and X-ray flashes (XRFs) for separate groups of bursts with respect to duration and hardness ratio in the BATSE and RHESSI datasets are discussed.



The hardness ratio $H_{21,\mathrm{CURR}}$ vs. T_{90} durations of 1932 BATSE bursts with identified group of short (*crosses*), intermediate (*full circles*), long bursts (*open circles*), and ones without assigned group-membership (*triangles*). The *horizontal solid line* is the XRF limit. The *objects above this line* are not classified as XRFs; the *objects below this line* are classified as XRFs.

Řípa & Mészáros 2016, Ap&SS, 361, 370

- Testing of isotropy can be done for separate GRB groups as well.

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.
- Our results hints towards a probable anomaly near the Galactic coordinates $l \approx 30°$, $b \approx 17°$ and radius $r \approx 20° - 40°$.
- The inferred probability for the occurrence of such an anisotropic signal (in a random isotropic sample) was derived to be less than 1%.
- However, 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.
- Further investigation is highly desirable to confirm or reject this result, e.g. using a larger *Fermi* / GBM data sample and data samples of other GRB missions and also looking for possible systematics.