Angular Anisotropy of Very Short Gamma Ray Bursts

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***Abstract*— In the present work we have studied quantitatively the unexpected divergence of isotropy found recently for the class of very short Gamma Ray Bursts (vsGRB). The 'prior-free' determination of the significance of this anisotropy is given. We find that the chance probability of the clustering such as is seen for vsGRB is about few times 10^{-5}; thus the effect itself is on the 4σ level.**

I. Introduction

The absence of an anisotropy of directions of Gamma Ray Bursts (GRB) was rather unexpected when the GRB were discovered and the attention of physicists was drawn to the most powerful events in the Universe (since the Big Bang). Since that time - the discovery not the Big Bang - the question of the GRB origin has been a mystery up to almost now, the progenitors of some of them having just been seen. Since about 1997 as a result of BeppoSAX satellite observations it is believed that the GRB of duration longer than about 2 seconds originate as result of the explosive collapse of the cores of young massive stars in star-forming galaxies at redshift of $z = 1-2$. Quite recently the shorter bursts were identified with something closer ($z \approx 0.2$), and consistent with the hypothesis of the merger of two neutron stars, or of a neutron star with a black hole. Both classes of GRB agree very well with the isotropic distribution of their directions. Thus the isotropy seems to be an attribute of GRB.

However a third class of GRB bursts was found - the very short burst (vsGRB). The confusion was stronger when it was found that this, not very numerous, class seems to be anisotropic on the sky [1].

The effect is so astonishing that it is worth knowing precisely the degree of belief of the vsGRB clustering seen by "naked eye" in the Fig. 1.

II. The method

To study the grouping of any items it is convenient to use a correlation measure. The ones we prefer are factorial moments

$$F_q(\Delta) = \frac{1}{M}\sum_{m=1}^{M}\frac{\left\langle n_m^{[q]}\right\rangle}{\langle n_m\rangle^q} = \\ = \frac{1}{M}\sum_{m=1}^{M}\frac{\int d\Omega\; n_q(i_1,i_2,\ldots,i_q)}{\int d\Omega\; n(i_1)n(i_2)\ldots n(i_q)}, \quad (1)$$

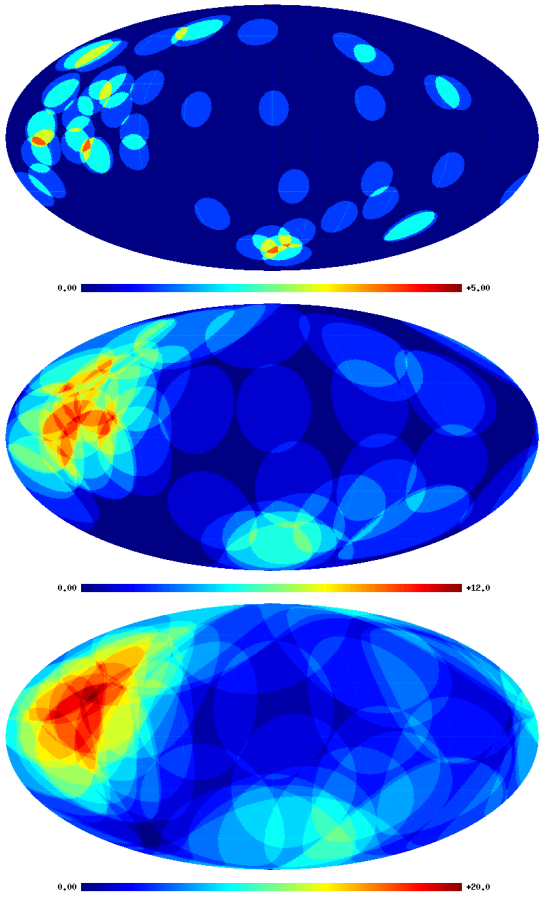

Fig. 1. Short gamma ray burst counting (see text) within 10° (top), 25° (middle), and 40° (bottom) radius cone around each vsGRB.

and cumulants

$$K_q = F_q - \sum_{m=1}^{q-1}\binom{q-1}{m} K_{q-m}\, F_m. \quad (2)$$

The numerator in Eq.(1) can be actually computed simply by counting q-tuples that have a "width" smaller than Δ [2]:

$$\int d\Omega\; n_q(i_1,i_2,\ldots,i_q) = \\ = \left\langle q! \sum_{i_1,i_2,\ldots,i_q} \Theta\left(\Delta - \mathrm{width}(i_1,i_2,\ldots,i_q)\right)\right\rangle. \quad (3)$$

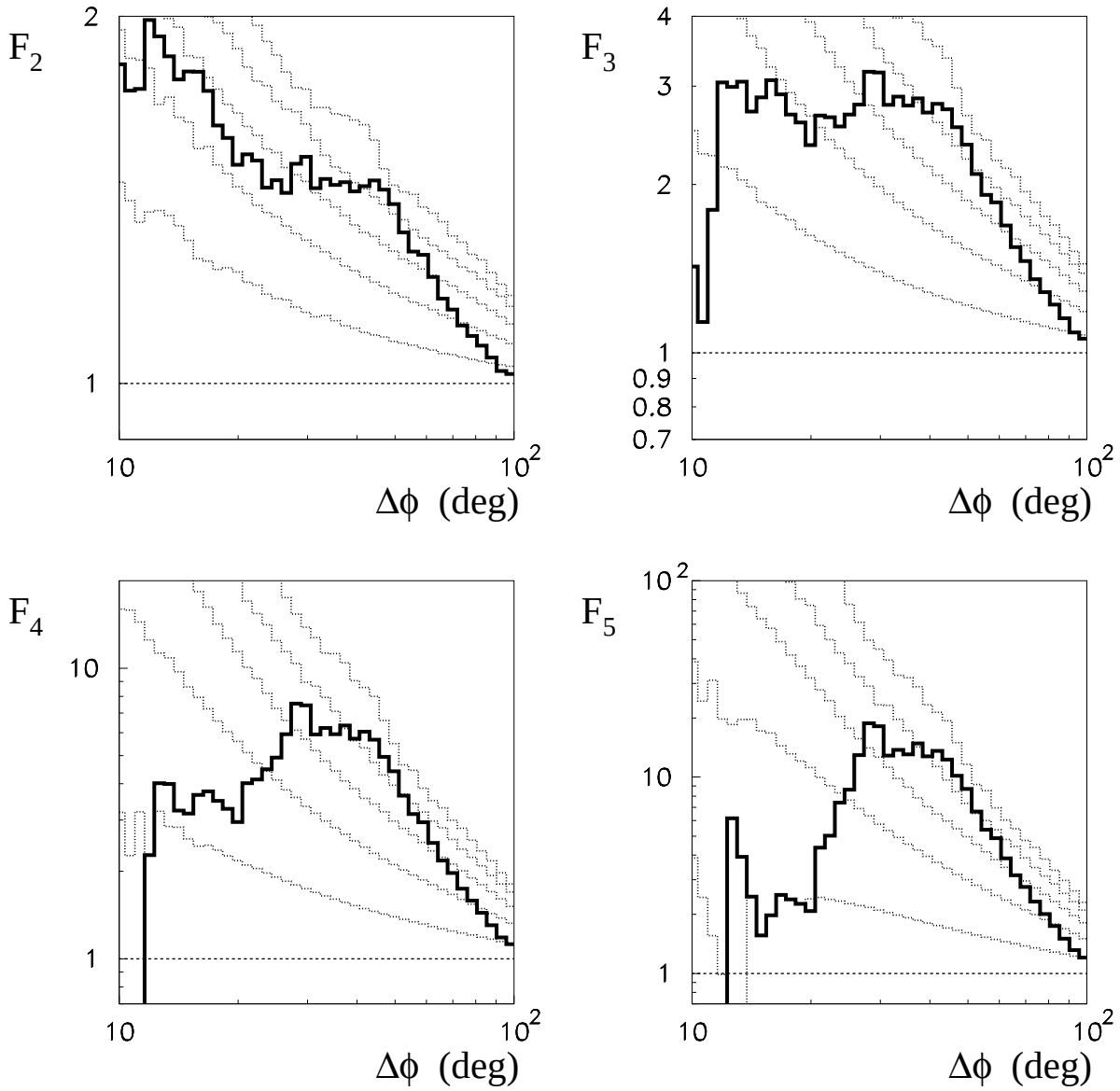

Fig. 2. First four factorial moments for vsGRB distribution on the sky. Thin dotted lines show the 0.1, 0.01, 10^{-3}, 10^{-4}, and 10^{-5} chance probability limits.

where Θ is the Heaviside unit step-function.

Following this procedure the denominator can be calculated in the same way but using the "artificially decorrelated" sample of events. The "decorrelation" can be obtained using the same number of items distributed randomly on a sphere, or with the randomization performed along only, e.g., Galactic longitude, conserving eventual inhomogeneities in galactic latitude distribution and (this way was chosen for the present work) or by mixing longitudes and latitudes from different items. The averaging can be performed using many such decorrelated samples. This procedure gives the possibility of obtaining significant limits for F_q not only the precise average value of the expected uncorrelated background (denominator in Eq.(1)).

There is some freedom in defining the "width" of the n-tuple. This is related to the particular problem in question. The measure of the clumping should reach a minimum for the shape of the cluster which we are looking for. The first is to look for any evidence of clustering at all, thus the radial symmetry of the cluster, as the first approximation, can be assumed.

This can be done using, e.g., the so-called "star" integration method:

$$\mathrm{width}_{\mathrm{star}}\,(i_1, i_2, \ldots, i_q) \;=\; \max_{k=2,\ldots,q} \left(\Delta\phi(i_1, i_k)\right), \qquad (4)$$

where $\Delta\phi(i,j)$ is the angular distance on the sphere between the direction of i^{th} and j^{th} events.

This measure requires that the distance between the first (central) item and any other in the sequence should be less than Δ.

To search for the events grouped along some linear structures on the sky (as e.g. Galactic or Supergalactic plane) the "snake integral" can be helpful:

$$\mathrm{width}_{\mathrm{snake}}\,(i_1, i_2, \ldots, i_q) \;=\; \max_{k=2,\ldots,q} \left(\Delta\phi(i_{k-1}, i_k)\right). \tag{5}$$

It requires that the subsequent events in a sequence $\{i_1, i_2, \ldots, i_q\}$ should be closer than Δ to each other.

If there is a real sign of linear structures in the studied sample (vsGRBs) then the significance of clustering calculated according to the snake integral should be higher than the significance found for the star integral.

III. Results on vsGRB self-correlation studies

To see the distribution of directions of very short GRB we plot them with 10°, 25° and 40° surroundings counting the number of intersections. This is shown in Fig. 1.

There is clear evidence of grouping in the Second Quadrant slightly above Galactic plane and a smaller group on the southern hemisphere at about Galactic latitude $b \approx -70^\circ$.

To estimate the significance of clustering, or in other words the chance probability of creating such clustered events, the factorial moments F_q up to fifth order were calculated and are shown in Fig. 2 as thick histograms.

For a pure random (decorrelated) event distribution, all values of F_q should be on average equal to 1, by definition. Due to the limited statistics of events the exact determination of confidence limits can be done by Monte Carlo methods.

The values of F_q appearing in Monte Carlo simulations with the chance probability of 0.1, 0.01, 10^{-3}, 10^{-3}, and 10^{-5} are shown in Fig. 2 by thin histograms. These lines can be treated as limits on levels of 0.1, 0.01, 10^{-3}, 10^{-4}, and 10^{-5} for the acceptance of the hypothesis of the isotropy of the vsGRB directions.

It is seen (Fig. 2) that the observed factorial moments chance probability is smaller than a few times (it could be said ≈ 3 if it is of interest) 10^{-5}.

We can conclude that we see, as a 4σ effect, group(s) of very short GRB of the size which is related to the minimum chance probability found in all plots in Fig. 2 of about 45°. This 'size of the cluster' is found with the "star" integration method, so it can be interpreted as a "maximum radius" of the blob.

Then another question arises: if there is any structure within this cluster. Do vsGRBs come from the one extended region or rather from a few sources within the region of 40°-50°. To answer this question the factorial cumulants can help.

They represent genuine correlations within the studied sample. This means that, e.g., K_3 exhibits the correlation of triplets with the effect of two-point correlation subtracted, K_4 - four point genuine correlation with 3- and 2-point correlation subtracted, etc. The interpretation of K_m have to be taken with care mainly due to the very limited statistics of events which we have in hand.

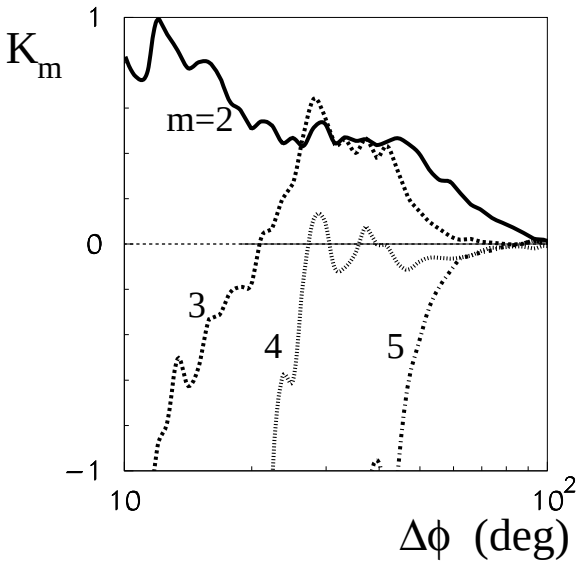

Fig. 3. First four factorial cumulants of the vsGRB direction distribution.

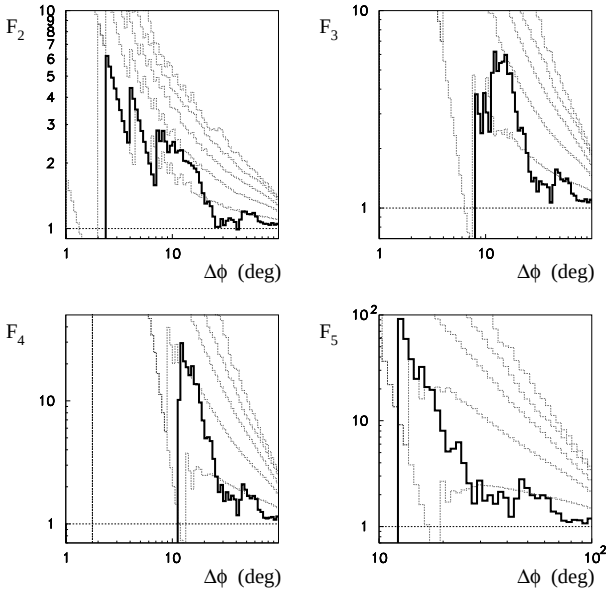

Fig. 4. Factorial moments for vsGRB sky map except of II Quadrant shown as in Fig. 2.

In Fig. 3 factorial cumulants up to the 5^{th} order are shown. It is seen that the values of 4^{th} and 5^{th} cumulants are consistent with the lack of any genuine correlation of 4^{th} and 5^{th} order (K_4 and K_5 values are consistent with zero). This suggests that the group (groups?) of very short GRB seen in Fig. 1 consists "in real" probably of a few smaller groups of multiplicity about 2-3.

To check if the overabundance of the very short GRB related

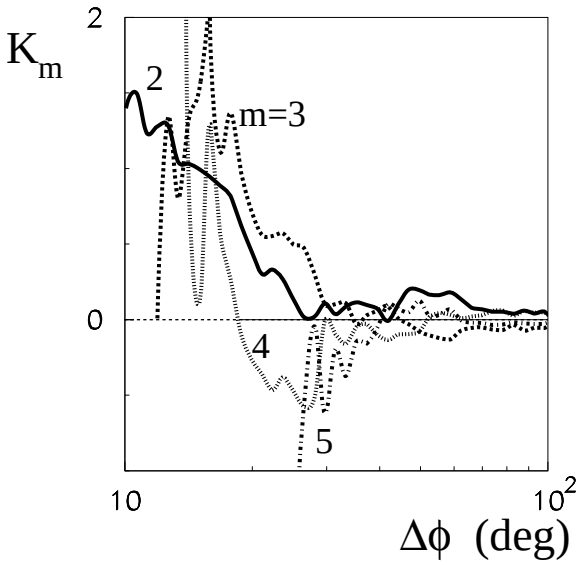

Fig. 5. Factorial cumulants for vsGRB sky map except Quadrant II shown as in Fig. 3.

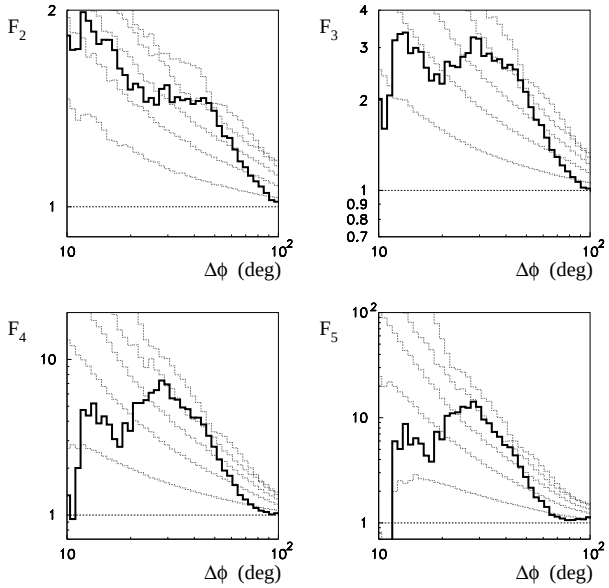

Fig. 6. Factorial moments for the vsGRB sky map calculated using the "snake" integral measure shown as in Fig. 2.

to the cluster seen in the factorial and cumulant plots is indeed the group of GRB identified by eye in Fig. 1 in the Second Quadrant ($90^\circ < l < 180^\circ$) we repeat the factorial moments and cumulants calculation for the sky without the second Quadrant. Results are shown in Figs. 4 and 5.

The small effect of the clustering of size below about 20° of the significance on the chance probability of about 1% (2.5σ) is seen very clearly. It is related to the mentioned small cluster of 5 events around $b \approx -70$. The comparison of Figs. 3 and 4 confirmed that the strong vsGRB correlation effect is related to the group in Quadrant II.

The cluster width measure used in all the above factorial calculations was the star integral measure. We have repeat them again using the snake integral instead looking for elongated structures. Results are shown in Fig. 6.

Comparing with the factorial moments given in Fig. 2 one can see that there is no change of the significance of grouping among vsGRB. Thus we can conclude that there is no evidence for any elongated, or linear structures in the vsGRB sample under study.

IV. Conclusions

Determination of the significance of the anisotropy of vsGRB directions has been performed using the factorial analysis method. The method allows us to determine the *'prior-'* and *'scale-free'* clustering probability.

We find that the chance probability of the clustering such as seen for very short GRB is about a few times 10^{-5} and thus the effect itself is on about the 4σ level.

Additional studies on higher rank correlations suggest that the observed enhancement of vsGRB in the Second Quadrant is produced rather by few extended sources than a single one. No elongated structures are seen in the vsGRB data sample.

V. Acknowledgments

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