Search for Gamma-Ray events in ALBORZ Observatory Data

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***Abstract*. At ALBORZ Observatory in Tehran ($51^\circ\ 20^{'}$, $35^\circ\ 43^{'}$, 1200 m) we accumulated a complete year of data by a 4-fold square array of Water Cherenkov Detectors (WCDs) with the side 6.08 m. It is recorded about 800,000 fine EAS events from 2006/11/12 to 2007/11/20 by the approximate recording rate of 0.03.**
Time differences between each two, three, four, five and ... have a very good agreement with gamma-function, which shows the correct random nature of the events. Of course we expect that about less than 1% of the EAS events ($\leq$9000 events) be electromagnetic and naturally not random, but the contribution is so small.
Then by Farley/Storey procedure [1] we found a signature of real sidereal data. So we tried to find the data by Li/Ma method [2] around EGRET gamma sources, but we didn't find any acceptable signatures (statistical significance more than 2). Then by investigation of number of recorded events in 6 time intervals 10, 30, 100, 300, 1000 and 3000 seconds (time boxes) we found 12 non-random events. This procedure did by the investigation of deviation from Poisson distribution function in at least three of the six time boxes. By the angular resolution of our experiment we can attribute these events to a few EGRET sources, which this stage is under investigation now.

***Keywords*: EGRET sources, Gamma-ray events, Poisson distribution function**

I. Introduction

EGRET experiment on board of CGRO *(Copmton Gamma Ray Observatory)* has recorded 271 gamma-ray point sources in the energy range between 30 MeV to 100 GeV [3]. Some of them are broad band energy range sources, like Active Galactic Nuclei ($AGNs$). Since energy range of our experiment is more than a few ten TeV, so there is a gap between the energy range of the EGRET and our experiments. Of course there are some source signatures between the gap, which are observable with Cherenkov telescopes in the energy range of the gap [4] or some data from ARGO-YBJ project in Tibet [5]. Also there are some recorded sources in the X-ray energy ranges by a few experiments like Chandra [6]. If it is a seen a few sources by our experiment and EGRET experiment or X-ray experiments or cherenkov experiments, we can investigate them in a few energy ranges.
In 271 reported EGRET sources there is 170 unknown ones, they may be AGNs, pulsars, BL-Lac objects, WR stars, OB associations and so on . If we argue the spread of the spectrum we are able to cancel some of the candidates, and it is a way to recognize the identification of the gamma-ray sources. Therefore we tried to find some source signatures in our data in this way in this work.
In this work we investigate the rate of our experiment, in three different durations, solar, sidereal, and anti-sidereal days. Of course there is another yearly duration too, which is due to seasonal effects. Solar day duration, shows the local effects like meteorological effects, sidereal duration contains two component, one is real sidereal (celestial) effect and the other is overlapping of solar and seasonal effects. By studying of the anti-sidereal effect it can be separated the real sidereal component. The real sidereal component shows celestial events and of the related celestial sources. Therefore we used the EGRET third catalogue as a reference, to find the source signatures and compared our results with them. Second we calculated the local, celestial and galactic coordinates of each recorded events, then drew the galactic map of the logged events (events map). By using the Farley/Storey method [1] we found some signatures of gamma-rays. Then we projected our few number of the events which were obtained by the poisson distribution function of the events in some time windows, and found 17 most probable events which are on the EGRET sources.

II. Experimental setup and data analysis

The array is constructed by four Water Cherenkov Detectors(WCDs) located at the roof of the physics department, Sharif University of Technology, 51° 20$^{'}$ E and 35° 43$^{'}$ N, elevation 1200 m a.s.l. (890 g cm^{-2}) in Tehran (Fig. 1(a)). It is the prototype of ALBORZ observatory at the elevation of 2650 m a.s.l. *(http://observatory.sharif.ir)*. Our WCDs are on a flat horizontal surface. Each WCD is a cylindrical metallic reservoir with 64 cm diameter and 1.2 m height. Configuration of the array is a square with 6.08 m side. The interior surface of each detector has been coated with

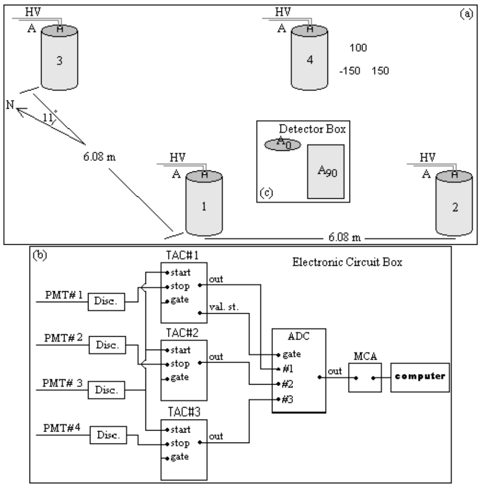

Fig. 1: **(Experimental setup)** Different parts of the figure respectively show **(a)**: schematic configuration of our detector array, **(b)**: data acquisition system and used electronic circuits, **(c)**(inside a): vertical (A_0) and horizontal (A_{90}) area surfaces of our detectors.

white paint, a 52 mm diameter EMI 9813B PMT faced inside the water is used for each WCD. If at least one particle passes through the detector, it creates a signal with a pulse height which its magnitude depends on the particle direction, number of the particles, and crossing track of the particle through the WCD [7]. Cherenkov radiation wavelength of the passed secondary charged particles inside water is about 470 nm. The amplification coefficient of the PMT in this wavelength is about 10^8 which creates an approximate pulse 100 mV and 20 ns width *(www.electronictubes.com)*. We used a fast NIM electronic circuit and a Multi Channel Analyzer (MCA) for the logging data procedure (Fig. 1(b)).

Cylindrical shape of the WCDs, causes a variational effective surface for different zenith angle EAS events, the effective surface is $A_{eff}(\theta) = P_0 A_0 \cos\theta + P_{90} A_{90} \sin\theta$ (Fig. 1(c)(inside 1(a))) where A_0 and A_{90} are the effective surface of the WCD for 0° and 90° events, and P_0 and P_{90} are the detection probabilities when secondary particles pass through A_0 and A_{90}. $P_0 = 0.88$ and $P_{90} = 0.93$ were obtained by a simulation of the WCDs [7], which the geometrical zenith dependency affects recording rate of the logged events.

III. A SIGNATURE OF CELESTIAL SOURCES IN THE LOGGED EAS EVENTS

There are so many sources or sinks of the EAS events around us. Some of them have period of a solar day, like atmospheric effects (daily variation of pressure and temperature), some others have period of a year, and some others too have a period of sidereal day (observation of celestial events). The obtained event rate is formed by

$$I = I_0 + [A + B\cos 2\pi(t+\phi_2)]\cos 2\pi(Nt+\phi_1) + C\cos 2\pi((N+1)t+\phi_3) \quad (1)$$

The first part I_0 is the uniform distribution of primary charged particles, which does not affect on the recording rate. This part is dominant part in our data, this shows the uniform distribution in the rate independent of existence of any sources or sinks. The second part contains two components, the first one ($A + B\cos 2\pi(t+\phi_2)$) is the seasonal effect with period of a year, and the senond one ($\cos 2\pi(Nt+\phi_1)$) is the solar daily effects with the period of 24 hours (365 solar days a year). The third part in equation 2 ($C\cos 2\pi((N+1)t+\phi_3)$) is the sidereal daily effects with the period of about 23 hours and 56 min (366 sidereal days a year). The equation 2 can be writte in the form of:

$$\begin{aligned} I = I_0 + A\cos 2\pi(Nt+\phi_1) + \\ \frac{B}{2}\cos 2\pi((N+1)t+\phi_1+\phi_2) + \\ C\cos 2\pi((N+1)t+\phi_3)) + \\ \frac{B}{2}\cos 2\pi((N-1)t+\phi_1-\phi_2) \end{aligned} \quad (2)$$

It shows, a sidereal part with a virtual component, from the superposition of seasonal and solar daily effects, so for separating of the net sidereal component we have to eliminate it. For the process we take help from the third part. It is anti-sidereal part with the period of about 24 hours and 4 min (364 anti-sidereal days a year). For the investigation, it was selected all of the complete solar, sidereal and anti-sidereal days in 6 two-month durations and it was found 6 values for C and ϕ_3, where $C = \bar{C} \pm \sigma_C$ and $\phi_3 = \bar{\phi}_3 \pm \sigma_{\phi 3}$. We distributed the abandonce of number of events in a period of a year for the three different days. After superposition of all of the obtained rates we obtained the mean distribution for all of the three days in two hours bins from 0 to 24. The number of complete days for solar, sidereal and anti-sidereal days are 274, 275 and 267 days respectively in 62 runs.

In Fig. 2(a) it is shown the procedure of the separation of the C component of sidereal rate. and in Fig.2(b) it is shown the obtained 6 vectors **C** for the 6 two-month durations and the total C of the year. More details of the vectors are presented in Table I.

The results show, we are able to observe the celestial sky by investigation of a part of our logged events. Variations of vector **C** is related to: $i)$ Experimental error factors and $ii)$ Observation of local source signatures which are observable in different two-months exposure times, which is explained in the subsection 3.

Essentially EAS events have a high contribution of Cosmic primaries and a very low contribution of gamma-ray primaries. Also our data is not so much and accurate to observe special point sources by itself, but in the upper investigation it has been found a signature of the celestial sources. In Table 1 it is seen that the anisotropy in real sidereal days is about decade of percents, which is in agreement with the contribution of gamma-ray to cosmic-ray primaries.

TABLE I: Detail information of two-month durations

Start date	A_{sol}	ϕ_{sol}	A_{sid}	ϕ_{sid}	A_{ant}	ϕ_{ant}	A_{net}	ϕ_{net}
06/11/12	14.26	0	15.69	11	10.10	0	6.09	29
07/01/14	7.43	83	8.85	66	6.40	104	2.51	76
07/03/14	6.52	10	9.90	14	0.68	0	9.22	14
07/05/14	6.18	65	9.95	59	2.43	98	7.86	67
07/07/14	15.82	33	14.84	32	13.48	33	1.39	22
07/09/14	8.50	59	12.79	44	4.48	96	8.80	55

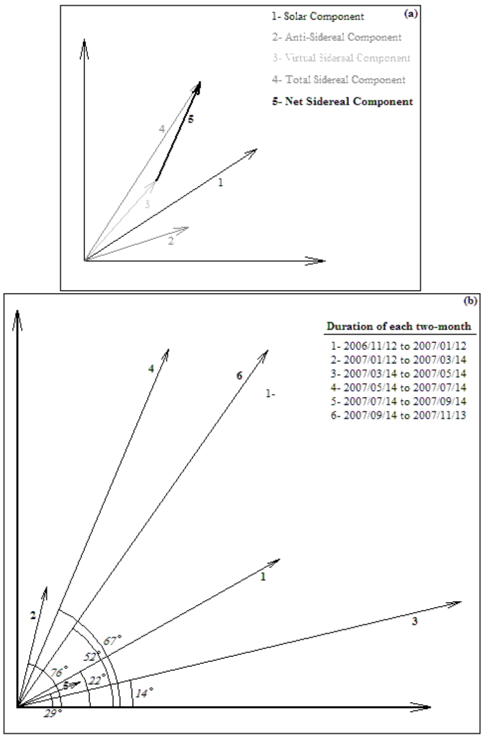

Fig. 2: **(a)**: Finding procedure of the net sidereal component. **(b)**: The obtained net sidereal components in six two-month durations.

In the energy range of the rays, the nearest experiments to ours are the EGRET experiment and Cherenkov telescopes experiments. Since approximately all of the observed sources by Cherenkov telescope results are in the EGRET list, so use we the EGRET catalogue as a reference and tried to find the EGRET point source signatures in our data. Of course our data can not distinguish the point sources and vast sources with the vastness less than our error. By study of the EGRET results, it is seen that the most important vast sources are in the plane of the Galaxy and specially around the core. Since FOV of our experiment around Galactic center is not complete, we concentrate on point sources. Then we surveyed for some gamma rays from the side of EGRET sources by the method of Farley/Storey.

A. Error estimation of the logged EAS events

We calculated the experimental error on the logging procedure, by exerting error factors of the experiment in our calculations of celestial and galactic coordinates of each EAS event. These error factors are: $i)$ Electronic time error in logging the EAS events, $ii)$ Thickness of the EAS fronts, $iii)$ Size of the WCDs, and $iv)$ Error in logging time of the EAS events.

More details of parts i and ii are presented in [8] which have been investigated for scinillator detectors. For part iii we arranged a few experimental setups to investigate the effect which is presented in subsection III-A1. Part iv of error factors is due to error in logging time of the EAS events. Our electronic has a capability of recording 20 events in a second, and we syncronized our computer with Universal time by *www.timeanddate.com*. By exerting the error factors on the calculations of the galactic coordinates of the events by error reflection procedure we found the the final error of $5.0° \pm 1.0°$ for the events. More details of the procedure has been presented in [9].

1) Calculation of the error due to size of the WCDs: In differnt setups, it is measured the Half Width Half Maximum (HWHM) of the time differences between each WCD and a reference 15×15 cm^2 scintillator. By another experiment we obtained the HWHM of two similar 15×15 cm^2 scintillators and obtained the contribution of each Cherenkov detector. By calculation of the HWHM between each two WCD from the upper results and calculation of coordinates of the logged events with HWHM errors we found the error 5.2°.

IV. Investigation of events rate and its distributions in different duration of times

To find the experiment rate, we obtained time differences between real time of each two following events. The distribution shows a correlation with an exponential function $R = R_0 \exp(-t/\tau)$ with $\tau = 25.50$ s. This shows the randomness of our data. Also we distributed these time differences between real times of 3, 4, 5 and 6 seque$3EGJ\ 0237+1635$, $3EGJ\ 0426+1333$ and $3EGJ\ 1308{+}8744$ntial events and by fitting the gamma-function $\Gamma(\Delta t_m, \tau, m) = N\frac{\Delta t_m^{m-1}}{(m-1)!}\tau^m \exp(-\Delta t_m/\tau)$ on them, we found $\tau = 25.50 \pm 0.02$ s. (Fig. 4)

Also we drew the abandonce of number of events in time intervals of 10, 30, 100, 300 and 1000 seconds. These distributions show a good fit with poisson function in all of the ranges, which are shown in Fig. 5. It means there isn't any bright set of events which shows a source by itself, and source events are mixed with the cosmic-ray background. But we found some common events in the 5 windows in the 6 two-month durations.

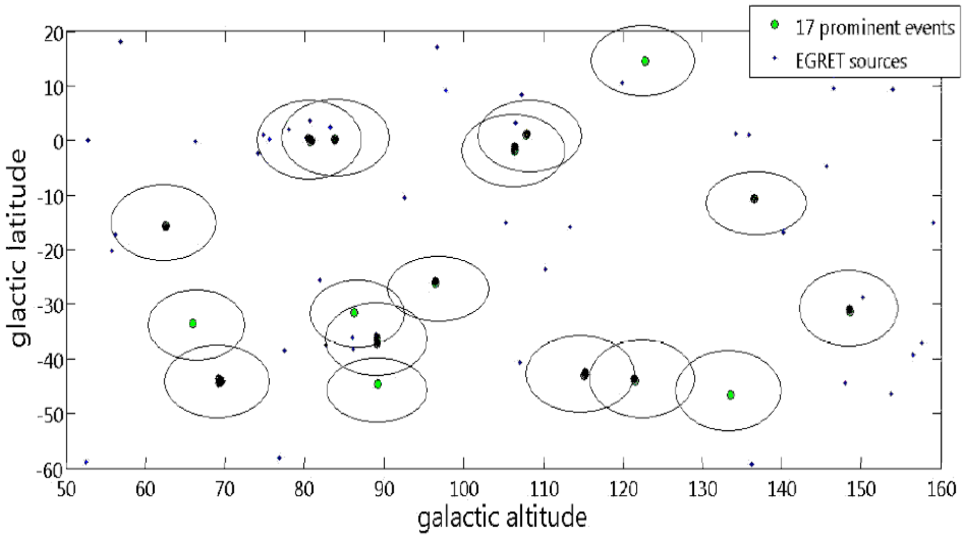

Fig. 3: Correlation of the found prominent events by EGRET sources by considering of the error factor.

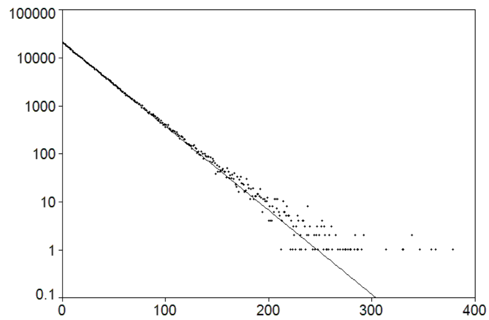

Fig. 4: The fitted exponential function on the real time differences between each two consecutive events, the obtained rate is 0.0403 Hz.

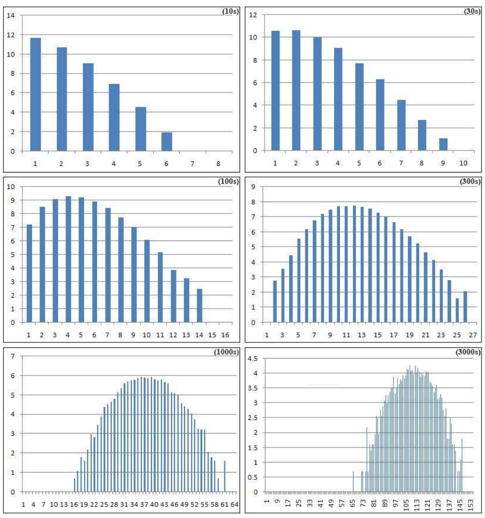

Fig. 5: Poisson distribution of the recorded data for time durations of 10, 30, 100, 300, 1000 and 3000 seconds.

V. Results

A. Correlation of the found events with EGRET point sources

By a survey over the six two-month durations we found 17 events which were common in three windows and tried two find the correlation between them and the point sources of EGRET Fig 3. Of course one of the problems of our investigation is our uncertainty in the positioning of the events in the galactic map.

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