Proceedings of ICRC 2001: 1 © Copernicus Gesellschaft 2001

ICRC 2001

A Wide Sky Survey to search for TeV gamma-ray sources by the Tibet air shower array

The Tibet ASγ Collaboration

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Abstract. A wide sky survey was performed using a quick analyzing method of equi-declination method applied to the data of the Tibet-II high-density array. Nineteen prominent directions, including the direction of Crab Nebula, were found to have significance values greater than 4.0.

1 Introduction

Recently several TeV gamma-ray sources have been found using air Cherenkov telescopes [1]. Crab Nebula [2], Vela pulsar [3], SN1006 [4] and PKS1706 [5] are examples in our galaxy, and AGNs of Mrk421 [6], Mrk501 [7] are examples of extragalactic sources. All sources found in our galaxy are ones of constantly emitting TeV gamma-rays. There are variable gamma-ray sources that are active repeatedly or temporarily; Mrk421 and Mrk501 are examples of the former and GRBs are of the latter. The Tibet air shower array have been observing TeV gamma-rays and have succeeded in detection of gamma-ray emission from Crab nebula and Mrk501 [8][9]. This array has several advantages; very wide field of view of greater than one steradian and very high duty cycle of nearly 90%. Due to this advantages, the Tibet air shower array suites to a detection of variable or sporadic type TeV gamma-ray sources in addition to sources of constant emission.

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2 Tibet Air Shower Array and Data Selection

Tibet air shower array is located at Yangbajing International Cosmic Ray Observatory (90.53 E, 30.11N) at an altitude 4,300 m a.s.l, and has been operated since January 1990. The Tibet-II high-density array consists of 109 scintillation detectors with unit of 0.5m^2 are settled at every grid points of 7.5m span covering an area of 5,175m^2 [9]. The triggering event rate is 115 Hz and mode energy is 3TeV. The event selection was made imposing the following two conditions. First, four-hold coincidence of any four FT-detectors each of which gives signal of more than 1.25 particles per 0.5m^2. Second, the incident zenith angles of air showers are smaller than 30°. Data used in this analysis are obtained in the time periods from February 1997 through October 1999 consisting of about 780 days data.

3 Process of the Analysis

Data are analyzed using equi-declination method for the estimation of background levels at on-source directions. All celestial directions are separated into small directional cells (SDCs) of size $0.1°$ (declination) $\times 0.1°$ (right ascension). The event numbers of on-source and of background are obtained by the Equi-declination method. Distrubution of air shower event number is obtained for the unit of SDC. An on-source window is consist of a set of SDCs which are included in or contact with a circle of radius 1 degree (real angle) centered at the center of on-source window. Background event number of an on-source window is estimated from densities of off-source directions which are consisted from 20 windows having the same shape as the on-source window. Centers of off-source cells are set at the same declination as the center of the on-source window but different for right ascension as $\alpha_{on} \pm\ 2.00° i$ where i is 2 through 11 and α_{on} is the right ascension of on-source center. On-source background density is estimated by the 2nd order curve function which is obtained by least-square fitting to the 20 off-source windows. This method to estimate background density of on-source window allows us a very fast data process of wide celestial field of view offered by the Tibet array. Significance is calculated using the following equation for the methods.

$$Significance = \frac{Excess\ Number}{\sqrt{N_{off}}/m} = \frac{N_{on} - N_{off}/m}{\sqrt{N_{off}}/m}$$

, where N_{on} and N_{off} are event number observed in the window of on-source and off-source, respectively, and m is ratio of window size. Here by S_δ we present the significance obtained by the equi-declination method. By this way, candidate active direction of TeV gamma-rays can be detected at once for the data set. In this analysis, we choose only such directions as the S_δ is greater than 4.0 in this period. By putting this condition, number of candidates decreases.

4 Background Estimation

Significance distribution obtained for all directions is shown in Fig. 1 which has mean value 0.001±0.001 and standard deviation 1.09±0.04. This value of standard deviation is slightly greater than the best value of unit due to some systematical error included in the fitting. Fig. 2 shows the distribution of air shower event number as a function of right ascension. The relative amplitude of this distribution is about 2 %, and has a peak and a bottom at around right ascensions 280° and 220°, respectively. When a direction is located at some point around the peak, background value estimated from linear fitting to off-source densities will be lower than the exact one, and for the case of a direction around the bottom background value estimated by the same way will be higher than the exact one. Then we used curves of second order as the fitting function for off-source densities. For example, Fig. 3a, b and c are results of this fitting to three typical right ascension directions 83.6°, 202.0° and 305.2°, as illustrated in Fig. 2, with respective declinations 22.0°, 17.9° and 40.4°. χ^2 values with degree of freedom 20 given for these examples are less than 15 which shows our fitting method to be statistically reasonable.

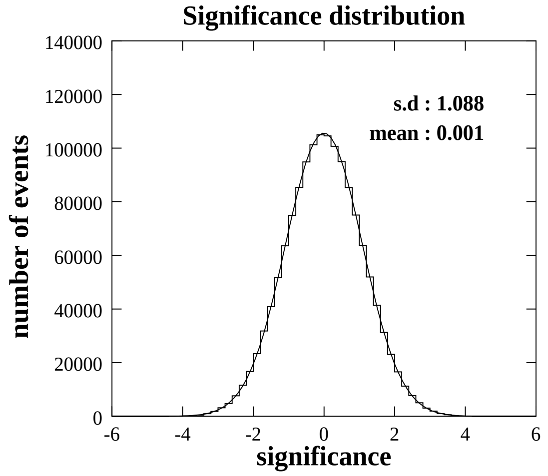

Figure 1. Significance, S_δ distribution.

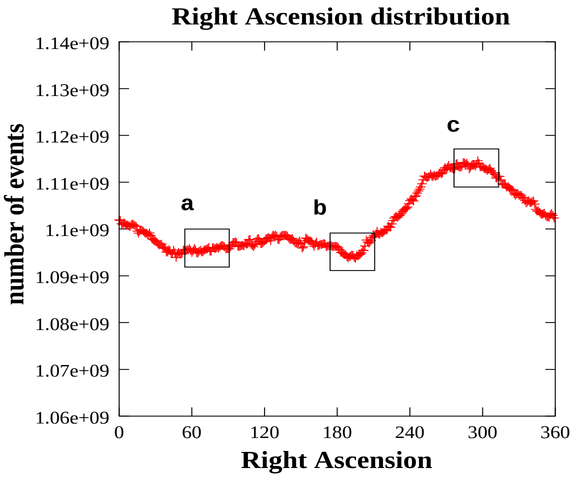

Figure 2. distribution of air shower event number.

5 Significance Distribution and List of the Prominent Directions

Significance values S_δ are obtained for the celestial directions which covers declination band 30°±20° for all right ascension region. We can find many prominent area where have high significance values greater than 4.0. The area of

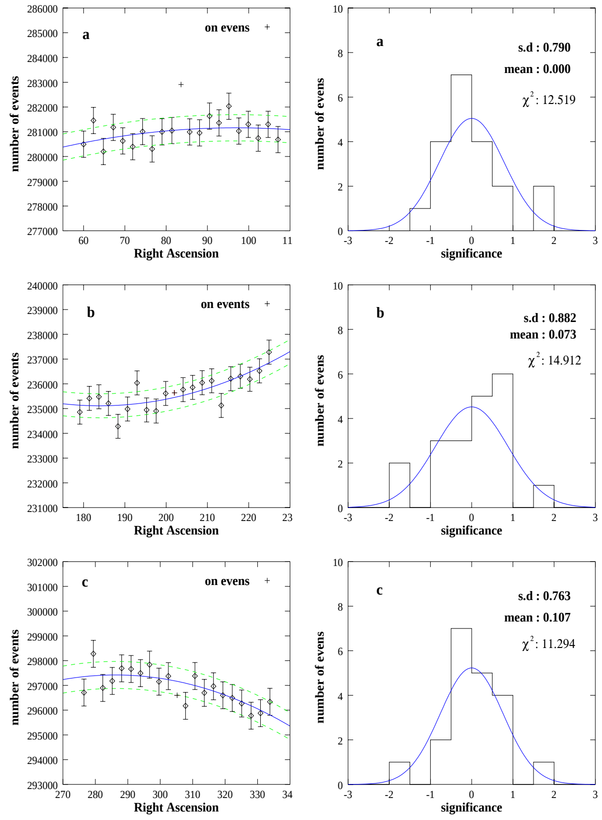

Figure 3. Left column : Results of fitting second order curves to (a) α=83.6°, δ=22.0°, (b) α=202.0°, δ=17.9° and (c) α=305.2°, δ=40.4°. Right column : corresponding significance distribution, χ^2 values with degree of freedom 20 given for these examples are less than 15 which shows our fitting method to be statistically reasonable.

Crab nebula (α=83.3°, δ=22.2°) gives significance value 4.7, and the highest direction in this map S_δ=4.9 is found in direction α=56.8°, δ=34.02°. nineteen areas in the map includes directions whose significance values are greater than 4.0. In Table 1 these 19 prominent directions are listed up with their highest significance values appeared in each area. Since it might be understood from the significance distribution of all directions as seen in Fig. 1, these 19 large significance value S_δ are possibly explained by statistical nature. While the significance value of the Crab direction is also included in the natural distribution of statistical fluctuation, the Crab direction is established standard candle of TeV gamma-rays. By the same manner it might be not refused that some of 18 directions are real sources of TeV gamma-rays.

6 Summary

We made a wide sky survey applying the equi-declination method to the data of Tibet-II high density array. Most of examined directions gave $S_\delta \leq$4.0, while 80 directions which satisfied $S_\delta \geq$4.0 were found. These prominent directions were grouped in 19 directions. Except for the direction of Crab Nebula, there was no corresponding TeV gamma-ray sources which have been confirmed by air Cherenkov telescopes, nor X-ray sources found by many satellite borne detectors. This result is very preliminary and, so far, we can not make any comment on new direction of TeV gamma-ray source. We will ascertain these 19 derections using new data now being obtained by Tibet-III data. We are also planning to examine the possible appearance of variable type new active TeV gamma-ray sources which might be repeatedly in active state as Mrk 421 and Mrk 501.

Table 1. Prominent directions and their highest significance values.

No.	R.A	Dec	S_δ	No.	R.A	Dec	S_δ
1	56.8	34.2	4.91	11	213.2	45.0	4.04
2	57.4	37.7	4.10	12	284.8	12.8	4.48
3	70.3	11.3	4.23	13	285.5	20.2	4.11
4	74.7	37.8	4.22	14	305.4	37.9	4.15
5	83.3	22.2	4.77	15	313.5	32.4	4.27
6	94.6	15.6	4.01	16	322.4	45.3	4.78
7	125.8	13.1	4.40	17	328.4	49.1	4.23
8	141.6	20.4	4.36	18	334.5	34.5	4.00
9	204.6	24.2	4.16	19	358.0	30.1	4.10
10	204.8	36.6	4.02				

Acknowledgements. This work is supported in part by Grants-in-Aid for Scientific Research and also for International Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology in Japan and the Committee of the Natural Science Foundation and the Academy of Sciences in China.

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