A Wide Sky Survey for Steady or Flare Type TeV Gamma-Ray Sources Using the Tibet-HD and Tibet- III Data

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Abstract

A survey was performed to search for TeV gamma-ray sources in the northern sky. In the search for steadily emitting sources 3TeV air shower data obtained by the Tibet-HD array and Tibet-III(Phase 1) array are analyzed. Nineteen prominent directions, including the direction of Crab Nebula, were found to have

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significance values greater than 4.0, but all significance values of these directions, except for Crab direction, are found to be consistent with the statistical fluctuation. From this result Crab is known to be the brightest TeV gamma-ray source in the sky area examined. To search for flare type sources we examined 19 prominent directions which gave high significance values in the Tibet HD array. A direction RA=313.5 deg., Dec=32.4 deg., have shown a flare like enhancement achieving significance 6.03σ in 90 days. Since the number of directions having such large value is statistically expected as 0.01, this direction has potencial to be a candidate of flare type TeV gamma-ray source in the northern sky.

1. Introduction

The Tibet air shower array have been observing TeV gamma-rays and have succeeded in detection of gamma-ray emission from Crab nebula [1], Mkn501 [2] and Mkn421 [3]. This array, in contrast to air Cherenkov telescopes, has very wide field of view greater than one steradian and very high duty cycle of around 90%. In addition to sources of constant emission, this advantage of the Tibet air shower array is suite to find unknown TeV gamma-ray sources of flare type. Using the Tibet-HD array and Tibet-III(Phase 1) array we surveyed the declination band of $30^\circ \pm 20^\circ$, through all right ascension range, to find new steadily emitting or flare type TeV gamma-ray sources.

2. Experiment

Tibet air shower array is located at Yangbajing (90.53 E, 30.11N) at altitude 4,300 m a.s.l..@The Tibet-II high-density (HD) array which covers an area of 5,175m^2 consists of 109 scintillation detectors with unit of 0.5m^2 settled at every grid points of 7.5m span. The Tibet-III (phase1) array has the same type detectors and rrangement as HD array, but the number of detectors and detection area are about 4 times larger than HD array and 22,000 m^2, respectively. The details of arrays and their triggering conditions are presented in Amenomori et al [4] for the HD array and in Amenomori et al [5] for Tibet-III(phase1) array. The incident zenith angles of air showers are limited to be less than 30°. From these conditions the mode energy and angular resolution of selected showers results in 3TeV and 0.90 degree for both observation. Data used in this analysis are obtained in 780 days of Feb. 1997 through Sep. 1999 for HD array and in 173 days of Nov. 1999 through Jun. 2000 for Tibet-III(phase1) array.

3. Background Estimation

Event numbers of on-source and of background are obtained by the equi-declination method. On-source window is a circle of radius 1 degree (real angle), and background event number at the on-source window is estimated from event numbers, N_{off}, in 20 off-source windows, each having the same shape as the on-source. Centers of off-source windows are set at the same declination as of on-source but different in right ascension as $\alpha_{on} \pm 2.00^\circ i$ where i is 2 through 11 and α_{on} is the right ascension of on-source center. Background event number at on-source window, N_{bg}, is estimated by interpolation of N_{off}s by fitting a curve of 2nd order as a function of right ascension. Significance, s, is calculated using $s = (N_{on} - N_{bg})/\sqrt{N_{bg}}$, where N_{on} is number of events in on-source window. By this method candidates for active direction of TeV gamma-rays can be survayed in rather short computation time.

4. Search for steadily emitting source

@To search for steadily emitting sources we use air shower data both of Tibet-HD array and Tibet-III(Phase 1) array. Significance values are obtained for the celestial directions covering a declination band $30^\circ \pm 20^\circ$ for all region of right ascension. On-source centers are set on every lattice points with a separation of 0.1° both for declination and for right ascension. Number of directions that have high significance values of greater than 4.0 are 19, in which the highest value 5.43 is given by the direction of Crab nebula. Reference numbers, celestial coordinates(J2000), event numbers and significances of these directions are listed in Table 1. The significance distribution of all on-source directions is shown in Fig. 1, which indicates that these 19 directions, except for the direction of Crab, are consistent with statistical fluctuation. From this result we can conclude that Crab is the brightest TeV gamma-ray source in the examined sky area. Nevertheless, direction T6 is noticeable since it gives the secondary high significance ($s = 4.81\sigma$). This direction gave similar growth of significance both in HD (3.48σ) and Tibet-III (Phase 1) (3.39σ) but no corresponding source of other energy band is found. Three directions, T16; G 76.9+1.0 SNR$d = 1.06^\circ$, T17; Cygnus Loop SNR$d = 1.01^\circ$ and T19; 3EG J2248+1745 unknown $d = 0.68^\circ$, are near to an EGERT source and SNRs with angular distance $d \sim 1.0^\circ$.

5. Search for flare type sources

The Tibet HD array had once detected a flare event occurred at Mkn 501 in 1997 [2]. The daily cumulative excess curve of Mkn 501 is shown in Fig.2,

Name	R.A. (degree)	Dec. (degree)	$N_{\rm on}$	$N_{\rm off}$	σ
T1	53.20	49.00	639403	635976	4.30
T2	62.70	43.30	759424	755370	4.66
T3	77.70	21.20	760459	756952	4.03
T4	83.60	22.00	771671	766919	5.43
T5	88.00	43.70	756956	753190	4.34
T6	88.70	30.10	855288	850847	4.81
T7	89.60	25.30	812005	808368	4.05
T8	96.90	17.60	704036	700639	4.06
T9	115.40	12.00	579002	575730	4.31
T10	160.20	23.80	797606	793982	4.07
T11	171.50	30.00	857592	853793	4.11
T12	199.40	11.20	554951	551903	4.10
T13	216.00	31.70	858123	854313	4.12
T14	254.30	40.80	799208	795494	4.16
T15	276.60	13.30	605034	601861	4.09
T16	304.30	38.80	824309	820225	4.51
T17	313.50	32.40	848458	844214	4.62
T18	322.40	45.30	725759	722110	4.29
T19	342.70	18.30	712286	708840	4.09

Table 1. Tibet HD + Tibet III(phase1) directions with significances $s \geq 4.0$. T4, giving the highest significance, corresponds to the Crab direction.

where a rapid rise of significance had amounted to 4.7 σ in 70 days which has been coincident with other detections reported by air Cherenkov telescopes [6][7][8]. @

In the analysis searching for flare type sources we examine Tibet-HD data. If a large flare is occurred at a celestial direction, its significance value remains in high value still at the end of Tibet-HD observation. Then to find large rises due to gamma-ray flares, we examined cumulative excess curves of 19 prominent directions that gave significance values greater than 4.0 at the end of Tibet-HD observation. As a result, one direction, named THD15, have shown the same type of very rapid rise as the 1997 flare of Mkn 501, as shown in Fig.2. The rise of THD15 has amounted to 6.03σ in 90 days of MJD50820 through 50910, as seen in Fig. 3.

To estimate an expected number that such high significance appears in any 90 days of the whole observation period 780 days, we made a simulation that generates 8×10^7 curves of daily cumulative excess assuming Gaussian fluctuation

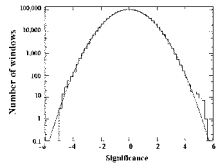

Fig. 1. Significance, s, distribution obtained from the combined data of Tibet-HD and Tibet-III(phase 1). The bump seen around $s \sim 5.0\sigma$ is contribution from directions in a circle of 1 degree centered at Crab nebula. Fitted curve is Gaussian of $\sigma = 1.079$.

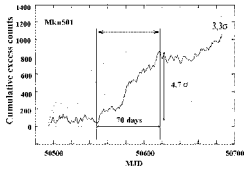

Fig. 2. Daily cumulative excess of the 1997 flare of Mkn. 501 observed by Tibet-HD. A rapid rise seen in days from MJD50550 through 50620 gave significance ~ 5.0. This time profile is available as a template to find gamma-ray flare in the field of view of the Tibet arrayD

of standard deviation 1.00. We obtained 3,849 curves that have significance values greater than 4.0σ at the end of 780 days. In these curves, we found 2 curves that have very rapid rises of significance value greater than 6.0σ in any period of 90 days of the whole days. When we convert this 2/3849 to the experimental trial number 19, the statistically expected number of cumulative curve is found to be $(9.8 \pm 0.6) \times 10^{-3}$ where error is due to statistical one. Though this expected number is not small enough, it suggests us a possible occurrence of flare at THD15 direction. THD15 is near to the X-ray ridge of Cygnus Loop but it does not coincides to high intensity region of the ridge. Neither BL Lac nor EGRET sources are found around THD15. It is interesting that the direction is near to one of extremely high energy EAS cluster, BC1, of AGASA [9]. If this direction really had generated a gamma-ray flare, its flux averaged over the 90 days is amount to about twice larger than that of Crab nebula and about 1.2 times larger of 1997 flare of Mrk501.@ Map of significance distribution around THD15 direction is made using the data of the 90 days, and it was found that area of high significance greater than 5.0 spread over area 0.3°. From this spread, pointing

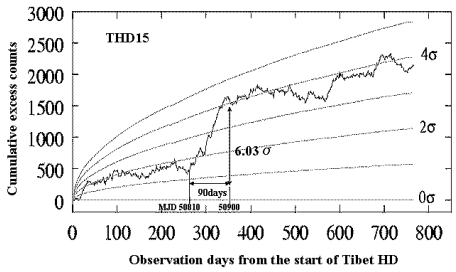

Fig. 3. Daily cumulative excess of direction THD15 in Table 2. A rapid rise, seen in days from MJD50820 through 50910, gave significance 6.03σ in 90days.

error of the HD15 direction is considered to be about0.3°.

6. Summary

We made a wide sky survey applying the equi-declination method to the data of Tibet-HD and Tibet-III(phase1) array. 19 directions which gave excess of significance $s \geq 4.0\sigma$ were found in the surveyed declination band $+10° \sim +50°$. Except for the direction of Crab Nebula, no corresponding TeV gamma-ray sources confirmed by air Cherenkov telescopes, nor X-ray sources found by satellite borne detectors and new direction of steadily emitting source was found. Crab is found to be the brightest steady emitting source in the surveyed declination band. As for the survey for flare type sources direction THD15 has shown a rise of significance amounting to 6σ in 90 days. Though the expected number ~ 0.01 is not sufficient to give us a full confidence, this direction has to be considered as a candidate of flare type TeV gamma-ray source in the northern sky.[†]

7. References

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[†]Acknowledgments: This work is supported in part by Grants-in-Aid for Scientific Research on Priority Areas from the Ministry of Education, Culture, Sports, Science and Technology in Japan and from the Committee of the Natural Science Foundation and the Academy of Sciences in China.

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