Observation of Multi-TeV Gamma Rays from Mrk 421 and Search for Other BL Lac Objects with the Tibet-III Air Shower Array

The Tibet ASγ Collaboration

M. Amenomori,[1] S. Ayabe,[2] S.W. Cui,[3] Danzengluobu,[4] L.K. Ding,[3] X.H. Ding,[4] C.F. Feng,[5] Z.Y. Feng,[6] X.Y. Gao,[7] Q.X. Geng,[7] H.W. Guo,[4] H.H. He,[3] M. He,[5] K. Hibino,[8] N. Hotta,[9] Haibing Hu,[4] H.B. Hu,[3] J. Huang,[9] Q. Huang,[6] H.Y. Jia,[6] F. Kajino,[10] K. Kasahara,[11] Y. Katayose,[12] K. Kawata,[13] Labaciren,[4] G.M. Le,[14] J.Y. Li,[5] H. Lu,[3] S.L. Lu,[3] X.R. Meng,[4] K. Mizutani,[2] J. Mu,[7] H. Nanjo,[1] M. Nishizawa,[15] M. Ohnishi,[13] I. Ohta,[9] T. Ouchi,[13] S. Ozawa,[9] J.R. Ren,[3] T. Saito,[16] M. Sakata,[10] T. Sasaki,[8] M. Shibata,[12] A. Shiomi,[13] T. Shirai,[8] H. Sugimoto,[17] K. Taira,[17] M. Takita,[13] Y.H. Tan,[3] N. Tateyama,[8] S. Torii,[8] H. Tsuchiya,[13] S. Udo,[2] T. Utsugi,[8] B.S. Wang,[3] H. Wang,[3] X. Wang,[2] Y.G. Wang,[5] L. Xue,[5] Y. Yamamoto,[10] X.C. Yang,[7] Z.H. Ye,[14] G.C. Yu,[6] A.F. Yuan,[4] T. Yuda,[13] H.M. Zhang,[3] J.L. Zhang,[3] N.J. Zhang,[5] X.Y. Zhang,[5] Y. Zhang,[3] Zhaxisangzhu,[4] and X.X. Zhou[6]

(1) Dept. of Phys., Hirosaki Univ., Hirosaki, Japan (2) Dept. of Phys., Saitama Univ., Saitama, Japan (3) IHEP, CAS, Beijing, China (4) Dept. of Math. and Phys., Tibet Univ., Lhasa, China (5) Dept. of Phys., Shandong Univ., Jinan, China (6) Inst. of Modern Phys., SW Jiaotong Univ., Chengdu, China (7) Dept. of Phys., Yunnan Univ., Kunming, China (8) Faculty of Eng., Kanagawa Univ., Yokohama, Japan (9) Faculty of Ed., Utsunomiya Univ., Utsunomiya, Japan (10) Dept. of Phys., Konan Univ., Kobe, Japan (11) Faculty of Systems Eng., Shibaura Inst. of Technology, Saitama, Japan (12) Dept. of Phys., Yokohama Natl. Univ., Yokohama, Japan (13) ICRR, Univ. of Tokyo, Kashiwa, Japan (14) CSSAR, CAS, Beijing, China (15) NII, Tokyo, Japan (16) Tokyo Metropolitan Coll. of Aeronautical Eng., Tokyo, Japan (17) Shonan Inst. of Technology, Fujisawa, Japan

Abstract

We search for multi-TeV γ-rays from 28 BL Lac objects as a TeV γ-ray point source candidate which were predicted from other wavelength (radio / optical / X-ray) data with the Tibet-III air shower array, based on the data set taken during the period from November 17 1999 to October 10 2001. We detected TeV γ-rays only from Mrk 421 at the statistical significance of 5.5 σ among the 28 objects and set upper limits at the 90% confidence level on γ-ray flux from other BL Lac objects.

1. Introduction

The Energetic Gamma-Ray Experiment Telescope (EGRET) [1] on board the Compton *GRO* satellite has detected MeV-GeV γ-rays from active galactic nuclei (AGNs) by nonthermal processes. These objects, called “blazars”, are highly variable and are bright radio sources. Overall spectrum of blazars have two broad continuous peaks, the lower-energy peak between infrared and X-ray is attributed to synchrotron radiation from accelerated high-energy electrons in

pp. 2595–2598 ©2003 by Universal Academy Press, Inc.

the AGN, and the higher-energy peak between GeV and TeV is due to the inverse Compton (IC) scattering of the same electrons off the soft photons. At TeV energies, several BL Lac objects in blazar class, such as Mrk 421, Mrk 501, 1ES 1426+428 and 1ES 1959+650 are confirmed TeV γ-ray sources by ground-based experiments. However, these objects except for Mrk 421 were not detected by the EGRET. In other words, it could miss TeV γ-ray sources, the IC peak position of which is beyond the EGRET sensitive energy window (20 MeV $\sim$ 30 GeV).

It has been suggested that TeV γ-rays from AGNs are absorbed rapidly due to their interaction with the infrared photon field in the intergalactic space. Therefore, multi-TeV γ-ray energy spectrum brings us important information on the column density and energy spectrum of the intergalactic infrared photons [2]. To study the intergalactic background field, we need many TeV γ-ray data from extragalactic objects at different redshifts (z). Costamante and Ghisellini [3] recently proposed a general and simple criteria to select the best TeV candidates using radio, optical and X-ray data. In this paper, we report the result on the flux of γ-rays from 28 BL Lac objects as a TeV γ-ray point source candidate in our sky survey with the Tibet-III air shower array.

2. Experiment

The Tibet-III air shower array (22,050 m^2), consisting of 533 scintillation counters which are placed at a lattice with 7.5 m spacing, has been operating since 1999 at Yangbajing in Tibet, China (90.522°E, 30.102°N) at an altitude of 4,300 m above sea level, an atmospheric depth of 606 g/cm^2. The details of the Tibet-III array is found elsewhere [4]. The trigger rate is about 680 Hz at a few TeV threshold energy. We collected 2.7×10^{10} events during the period from November 17, 1999 through October 10, 2001, corresponding to 456.8 live days. After some data selections, 5.52×10^{9} events remained for further analysis. The mode energy of air shower events is estimated to be about 3 TeV.

3. Results and Discussions

The background is estimated by the number of events averaged over off-source cells with the same angular radius as on-source, at the same zenith angle, recorded at the same time intervals as the on-source cell events, so-called "equi-zenith angle method" [4]. We calculated the statistical significance of TeV γ-ray signals from target source using the formula of $(N_{\rm ON} - \langle N_{\rm OFF}\rangle)/\sqrt{\langle N_{\rm OFF}\rangle}$, where $N_{\rm ON}$ and $\langle N_{\rm OFF}\rangle$ are the number of events in the on-source cell and the number of background events averaged over off-source cells, respectively.

Costamante and Ghisellini [3] produced a list of the best TeV γ-ray source candidates with flux estimates above 40 GeV, 300 GeV and 1 TeV using a simple phenomenological model traced by the radio luminosity [5]. However, they do not include the possible γ-ray absorption effect due to the infrared background. Among the 33 BL Lac objects predicted by them and 5 confirmed ones, 28 can be investigated in our sky survey (0<declination<60). The target BL Lac objects, the estimated flux above 1 TeV and our search results are listed in Table 1 under assumption of stable γ-ray emission. TeV γ-rays from Mrk 421 are detected at 5.5 σ statistical significance and positive correlation is found between changes of the X-ray flux by ASM/RXTE satellite and the Tibet TeV γ-ray flux [4]. No significant evidence is found for continuous γ-ray emission from other BL Lac objects. The significance distribution of excess signals from BL Lac objects is shown in Fig. 1 including Mrk 421. The significance distribution is consistent with the normal Gaussian except for Mrk 421 (chance probability considering the number of trials: 6×10^{-7}). As shown in Table 1, we set upper limits at the 90% confidence level on γ-ray flux above 1 TeV from other BL Lac objects than Mrk 421, assuming an integral power-law spectrum of $E^{-1.6}$ and comparing those with estimated TeV γ-ray flux. Our result rules out 2 source candidates among the 24 unconfirmed. This result excludes the null infrared photon hypothesis in the intergalactic space at the 90% confidence level if the phenomenological model proposed by Fossati et al. [5] reflects the reality, although we obviously need more statistics to draw any conclusion.

Acknowledgments: 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.

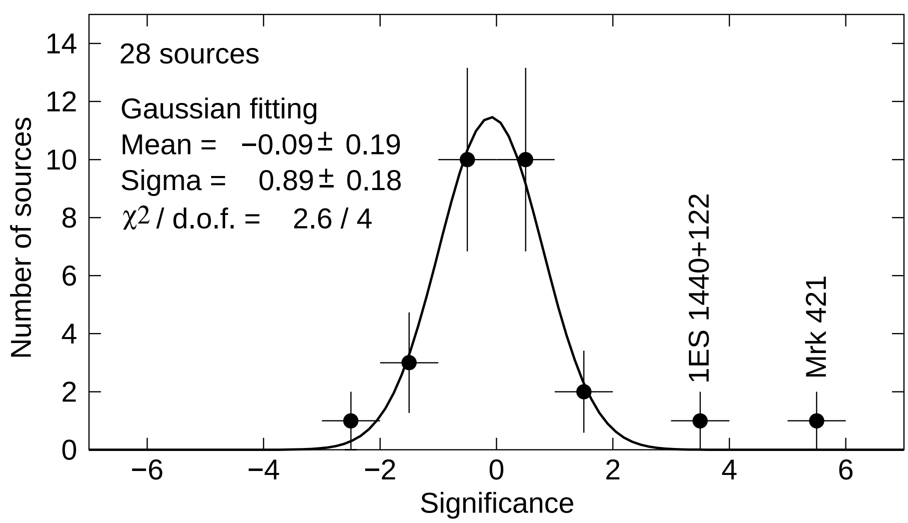

Fig. 1. The significance distribution of 28 BL Lac objects.

Table 1. TeV γ-ray source candidates and the search result of TeV γ-ray emission from them with the Tibet-III array in the years 2000 and 2001.

Source	z	$F_{\rm Est.}{}^{a}$ (>1TeV)	$F_{\rm Tibet}{}^{b}$ (>1TeV)	$E_{\rm Tibet}{}^{c}$ (TeV)	Tibet-III (σ)	EGRET Detection
Mrk 421	0.031	confirmed	–	3	+5.5	yes
Mrk 501	0.034	confirmed	1.25	3	+0.8	no
1426+428	0.129	confirmed	0.51	3	−1.8	no
2344+514	0.044	confirmed	1.38	5	+0.7	no
0033+595	0.086	0.48	1.09	7	−0.5	no
0120+340	0.272	0.06	0.74	3	−0.6	no
0136+391	–	0.12	1.34	3	+1.0	no
0214+517	0.049	1.43	0.65	5	−1.4	no
0219+428	0.444	0.01	0.88	3	−0.2	yes
0229+200	0.139	0.21	1.31	3	+0.8	no
0323+022	0.147	0.18	1.84	7	+0.7	no
0414+009	0.287	0.04	1.34	7	−0.3	no
0647+250	–	0.12	1.21	3	+0.7	no
0806+524	0.138	0.27	0.46	5	−2.6	no
0809+024	–	0.12	1.54	7	+0.2	no
0851+202	0.306	0.03	1.09	3	+0.3	yes
1011+496	0.200	0.02	1.48	5	+1.0	yes
1028+511	0.361	0.06	1.41	5	+0.8	no
1114+202	0.139	0.28	0.53	3	−1.8	no
1215+303	0.237	0.02	0.82	3	−0.5	no
1218+304	0.182	0.15	0.71	3	−0.9	no
1417+257	0.237	0.08	0.94	3	±0.0	no
1440+122	0.162	0.20	2.99	5	+3.2	no
1553+113	0.360	0.02	0.81	5	−0.9	no
1722+119	0.018	3.52	0.98	5	−0.3	no
1727+502	0.055	1.23	1.39	5	+0.8	no
1741+196	0.084	0.84	0.88	3	−0.3	no
2200+420	0.069	0.43	0.87	3	−0.2	yes

[a] ($\times 10^{-11}$ cm^{-2} s^{-1}) Estimated flux by Costamante and Ghisellini [3] (see §3).
[b] ($\times 10^{-11}$ cm^{-2} s^{-1}) Flux upper limits at the 90% confidence level assuming an integral power-law spectrum of $E^{-1.6}$ with the Tibet-III array.
[c] Mode energy corresponding to the diurnal motion of each object.

1. Hartman R.C. et al. 1999, ApJS, 123, 79
2. De Jager O.C., Stecker F.W., & Salamon M.H. 1994, Nature, 369, 294
3. Costamante L. & Ghisellini G. 2002, A&A, 384, 56
4. Amenomori M. et al. 2003, astro-ph/0304241
5. Fossati G. et al. 1998, MNRAS, 299, 433