OG.2.1.21

Detection of a new TeV gamma-ray source of BL Lac object 1ES 1959+650

The Utah Seven Telescope Array collaboration

T.Nishiyama[2], N.Chamoto[2], M.Chikawa[3], S.Hayashi[2], Y.Hayashi[4], N.Hayashida[1], K.Hibino[5], H.Hirasawa[1], K.Honda[6], N.Hotta[7], N.Inoue[8], F.Ishikawa[1], N.Ito[8], S.Kabe[9], F.Kajino[2], T.Kashiwagi[5], S.kakizawa[19], S.Kawakami[4], Y.Kawasaki[4], N.Kawasumi[6], H.Kitamura[16], K.Kuramochi[11], E.Kusano[9], H.Lafoux[1], E.C.Loh[12], K.Mase[1], T.Matsuyama[4], K.Mizutani[8], Y.Morizane[3], M.Nagano[18], D.Nishikawa[1], J.Nishimura[13], M.Nishizawa[14], T.Ouchi[1], H.Ohoka[1], M.Ohnishi[1], S.Osone[1], To.Saito[15], N.Sakaki[1], M.Sakata[2], M.Sasano[1], H.Shimodaira[1], A.Shiomi[8], P.Sokolsky[12], T.Takahashi[4], S.F.Taylor[12], M.Takeda[1], M.Teshima[1], R.Torii[1], M.Tsukiji[2], Y.Uchihori[16], T.Yamamoto[1], Y.Yamamoto[2], K.Yasui[3], S.Yoshida[1], H.Yoshii[17], and T.Yuda[1]

[1] *Institute for Cosmic Ray Research, University of Tokyo, Tokyo 188-8502, Japan*
[2] *Department of Physics, Konan University, Kobe 658-8501, Japan*
[3] *Department of Physics, Kinki University, Osaka 577-8502, Japan*
[4] *Department of Physics, Osaka City University, Osaka 558-8585, Japan*
[5] *Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan*
[6] *Faculty of Education, Yamanashi University, Kofu 400-8510, Japan*
[7] *Faculty of Education, Utsunomiya University, Utsunomiya 320-8538, Japan*
[8] *Department of Physics, Saitama University, Urawa 338-8570, Japan*
[9] *High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan*
[10] *Department of Physics, Kobe University, Kobe 657-8501, Japan*
[11] *Faculty of Science and Technology, Meisei University, Tokyo 191-8506, Japan*
[12] *Department of Physics, University of Utah, Utah 84112, USA.*
[13] *Yamagata Academy of Technology, Yamagata 993-0021, Japan*
[14] *National Center for Science Information System, Tokyo 112-8640, Japan*
[15] *Tokyo Metropolitan College of Aeronautical Engineering, Tokyo 116-0003, Japan*
[16] *National Institute of Radiological Sciences, Chiba 263-8555, Japan*
[17] *Department of Physics, Ehime University, Matsuyama 790-8577, Japan*
[18] *Department of Applied Physics and Chemistry, Fukui University of Technology, Fukui 910-8505, Japan*
[19] *Department of Physics, Shinshu University, Matsumoto 390-8621, Japan*

Abstract

BL Lac object 1ES 1959+650 with small redshift of z=0.048 has been observed using the Utah Seven Telescope Array detector with 3 m diameter at Dugway, Utah. We have observed 1ES 1959+650 for 56.7 hours in total from May, 1998 until August, 1998. We obtained evidence of VHE gamma-ray emission from 1ES 1959+650. Event excess with a significance of 5.3 σ for the data from MJD 50956 to MJD 50965 and of 5.0 σ from MJD 50996 to MJD 51023 from the direction of the object was obtained. Excess of 3.9 σ was obtained from the analysis of all data taken in 1998. Variability of the VHE gamma-ray emission was seen from the light curve.

1 Introduction:

More than 50 active galactic nuclei (AGN) have been detected as gamma-ray sources by the EGRET detector on board the Compton Gamma Ray Observatory with energies above 100MeV. Mrk 421(Macomb et al. 1995), Mrk 501(Quinn et al. 1996), and 1ES 2344+514(Catanese et al. 1998) have been identified as TeV gamma-ray sources of AGNs fo far. These sources are all BL Lacertae (BL Lac) objects, a subclass of the blazar class of AGN which are close BL Lacs. Redshifts of Mrk 421, Mrk 501, and 1ES 2344+514 are 0.030, 0.034, and 0.044, respectively. These AGNs are believed to have relativistic beams pointed very closely to the direction of the earth. Origin of TeV gamma-rays from these objects may be explained by the Synchrotron Self Compton (S.S.C.) model.

The blazars are characterized by their violent activities. Mrk 501 showed strong variability especially in TeV gamma-ray region in 1997.(Hayashida et al. 1998) Studies of variabilities of gamma-ray flux will contribute to understand acceleration mechanism of particles in AGNs.

We have searched many BL Lac objects with low redshifts ($z \leq 0.1$) at energies around TeV by Cherenkov telescopes in Utah. (Yamamoto et al., 1999) Beause the effect of attenuation of the VHE gamma rays by interaction with the background intergalactic infrared photons is thought to be small. (Stecker et al. 1996)

The object 1ES 1959+650 is one of the newly discovered BL Lac objects by an efficient X-ray/radio/optical technique at α=19h59m59.9s and δ=+65°08'55"(Schachter et al. 1993).

We report the results from the observation about the BL Lac object 1ES 1959+650 with redshift of z = 0.048 in this paper.

2 Experiment:

The Utah Seven Telescope Array detector is located at 1600m above sea level, Dugway, Utah (40.33° N, 113.02° W). Seven telescopes are arranged in a hexagonal grid with a separation of 70m to maximize the detection efficiency of TeV gamma rays. Observation data using three telescopes with respective separation of 120 m are used in this paper.(Aiso et al. 1997) Each telescope is the alt-azimuth mount with a 6m^2 main dish which consists of 19 hexagonal shape segmented mirrors. Absolute pointing accuracy of the telescopes is obtained to be typically 1 arcmin.

A high resolution imaging camera of 256ch photomultiplier tubes is installed at the focal plane with the field of view of $\pm 2°$ to measure detailed images of the Cherenkov light from gamma rays and cosmic rays. The signals from the 256ch camera are amplified just behind the camera and are fed to ADC and TDC modules mounted at the telescope base to measure the amplitude and the timing. The triggering requirement to record the event is four folds out of 256 tubes. Threshold level of the discriminators are set at 5 photo-electrons. The single counting rates in each tube are set to 3-5kHz in each channel. Threshold energy for detectable gamma rays is estimated to be 600 GeV for vertical showers.

The observation of 1ES 1959+650 was carried out from May 18, 1998 until August 30, 1998. We observed for 38 nights resulting a total observation time of 56.7 hr. We observed the object by a tracking mode called as the raster scan for which the telescope tracking center scans the square region of $\pm 0.5°$ in right ascension and declination coordinate centered on the target. Average event rate was about 9 Hz with three telescopes.

We have observed shower events around 1ES 1959+650, which are mainly cosmic ray protons and helium nuclei. Rejection of huge number of cosmic-ray background events is very essential to obtain a good S/N ratio. Therefore we used the techniques originally developed by the Whipple group (Hillas 1985, Weekes et al. 1989). The gamma rays are very efficiently distinguished from the background cosmic rays by this method.

From the shower events, we selected gamma ray candidates using the shape parameters of Cherenkov images and their directionality. We can determine the arrival direction of gamma rays and the cosmic rays with an elliptical accuracy of $0.1° \times 0.3°$ in each event. Therefore, 97% of the background events around the target can be rejected.

Images of the gamma rays are typically thinner than those of the cosmic rays, therefore they are rejected with 95% efficiency through the image selection. Typically 99.85 % of the background events around the target are rejected with the image and the arrival direction using the present analysis method. 35% of the gamma-ray events remain through this process.

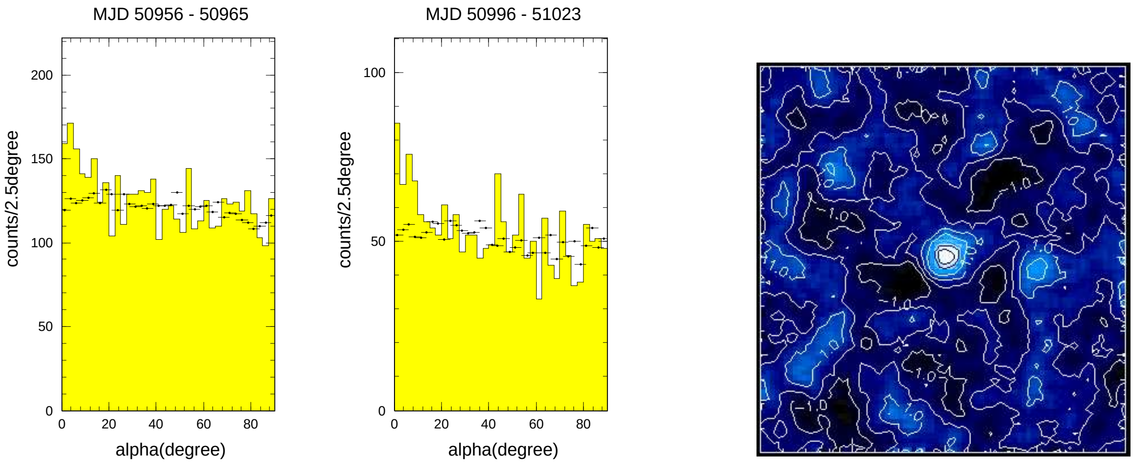

Figure 1: Left : $ALPHA$ distributions in two different periods are shown. Solid lines show the distribution for on-source events and dots with bars shows for off-source events. The excess events in the small alpha region less than 10° corresponds to the gamma-rays events from 1ES 1959+650. Right : Map of significance value of excess events in right ascension and declination plane of $4^{\circ} \times 4^{\circ}$ centered at the position of 1ES 1959+650.

3 Analysis:

Cherenkov light signals from gamma rays and cosmic rays are known from the Monte Carlo simulation to be concentrated within a 10 nsec interval. However background photons by star light and the air glow are randomly distributed in time and camera space. Therefore we required a time alignment with a software timing gate set at 40 nsec and a geometrical clustering of hit tubes to obtain clean Cherenkov images. After these imaging process, chance coincidence events due to the random coincidence were quite efficiently rejected and the pure Cherenkov events induced by gamma rays and cosmic rays remained.

Then we calculated the image parameters: $SIZE$, the centroid position of images (x, y), $WIDTH$, $LENGTH$, $CONC$, DIR and $ALPHA$. $SIZE$ was calculated by summing ADC counts of hit PMTs. The events with images located near the camera boundary were cut by requiring the condition $R = \sqrt{(}x^2 + y^2) \leq 1.8^{\circ}$, because the images near the camera boundary were distorted due to the boundary.

From the Monte Carlo simulation gamma rays showed more compact images than the hadronic showers, then we selected events which had a smaller $WIDTH$ and $LENGTH$ region of the experimental data. We took $WIDTH \leq W_{30} + 0.10 \times (log_{10}(SIZE) - 2.6)$, and $LENGTH \leq L_{50} + 0.16 \times (log_{10}(SIZE) - 2.6)$, where W_{30} and L_{50} corresponded to 30% and 50% points obtained by integrating the distribution of off-source hadronic events.

In addition, we imposed a condition $CONC \geq C_{50}$, where C_{50} corresponded to half events of the $CONC$ distribution, since gamma-ray initiated showers had a higher light concentration than hadron initiated showers. After these selections, 14-16$\%$ of events remained.

Then we selected events to get gamma-ray showers using DIR which corresponded to incident direction of showers obtained by the asymmetry of shower images.

4 Results and Discussion:

$ALPHA$ distributions centered at the direction of the object 1ES 1959+650 in two different periods are shown in Fig.1(Left). Excess events in the small $ALPHA$ less than 10° in the figure correspond to a significance of 5.3 σ for the data from MJD 50956 to MJD 50965 and 5.0 σ from MJD 50996 to MJD 51023. The excess events with a significance of 3.9 σ was obtained from the analysis of all data taken in 1998.

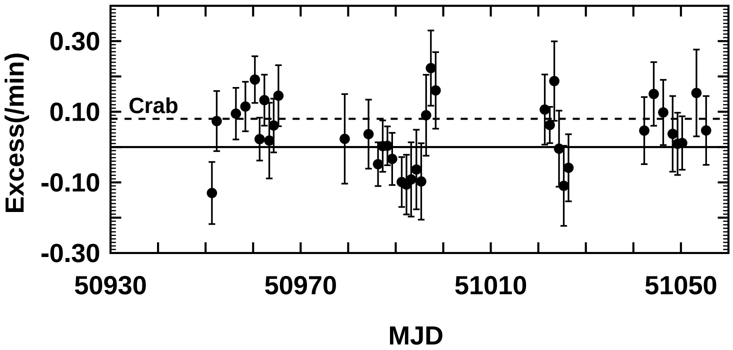

Figure 2: Time variation of the excess event rate for 1ES 1959+650 from May 18 to Aug. 30, 1998.

Significance map of the excess events in right ascension and declination plane of $4° \times 4°$ centered at the position of 1ES 1959+650 is shown in Fig.1(Right) for the summed data from MJD 50956 to MJD 50965 and from MJD 50996 to MJD 51023.

The excess event rate is plotted as a function of Modified Julian Day(MJD) in Fig.2. Gamma-ray flux variability of an order of day scale can be seen from this figure. Time variation of the excess event rate from the Crab Nebula was also obtained by the same process, which was consistent with having constant value within error. Average value of the excess event rate for the Crab Nebula was 0.081/min. The variation of VHE gamma-ray emission has also been observed for Mrk 421 and Mrk 501. The present result of such nature is consistent with the observations of these BL Lac objects.

Acknowledgments

The authors would like to thank the Hires group and people at Dugway for the help of observations. This work is supported in part by the Grants-in-Aid for Scientific Research (Grants #0724102 and #08041096) from the Ministry of Education, Science and Culture and is also partly supported by the Promotion and Mutual Aid Corporation for Private Schools of Japan.

References

Aiso, S. et al. 1997, Proc. 25th ICRC 4, 181,
Aiso, S. et al. 1997, Proc. 25th ICRC 4, 261
Catanese, M. et al. 1998, ApJ 501, 616
Hayashida, N., et al., 1998, ApJ 504, L71
Hillas, A.M. 1985, Proc. 19th ICRC 3, 445
Macomb, D.J. et al. 1995, ApJ 449, L99
Quinn, J. et al. 1996, ApJ 456, L83.
Schachter, J.F. et al. 1993, ApJ 412, 541
Stecker, F.W., de Jager, O.C., & Salamon, M. 1996, ApJS, 107, 227
Weekes, T.C. et al. 1989, ApJ 342, 379
Yamamoto, T. et al. 1999, Proc. 26th ICRC OG 2.1.25