Astroparticle Physics 11 (1999) 141–144

Astroparticle Physics

www.elsevier.nl/locate/astropart

Energy spectrum of TeV gamma rays from Mrk 501 obtained by stereoscopic analysis

Utah Seven Telescope Array Collaboration

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Abstract

We have observed flares of TeV-gamma rays from Mrk501 in 1997 using three telescopes of the Utah Seven Telescope Array at Dugway, Utah. Determination of the energy spectrum from such Active Galactic Nuclei (AGN) is very important, because the gamma-ray spectrum is expected to steepen around 10 TeV from objects like Mrk501 by the interaction of the infrared photons. We have developed the method to estimate energies of the gamma rays by stereoscopic analysis using

PII S0927-6505(99)00038-9

multiple telescopes. The differential index of the energy spectrum obtained is well expressed by -2.5 between 700 GeV and 3 TeV. This spectrum seems to become steeper above several TeV.

Keywords: AGN; BL Lacertae objects; Mrk501; Gamma rays

1. Introduction

Precise measurement of the gamma-ray energy spectrum in the TeV region from nearby extra-galactic objects is one of the important objectives. We expect the cutoff in their energy spectrum by the interaction with the infrared photons in the intergalactic space. The cutoff energy depends on the distance of the objects and the density of infrared photons [1]. If we can measure the cutoff energy precisely as a function of red-shift parameter z, we can determine the Hubble constant and the infrared photon density experimentally. The maximum energy of the electron acceleration in the AGN jet is another interesting topic. It will represent the physics state of the jet and the super massive black hole which is supposed to exist at the center.

The most promising way to measure the gamma-ray energy in the TeV region is the stereoscopic observation of the Čherenkov light from the air showers. We can determine the arrival direction and the core location of the air showers event by event with this method.

2. Experiment

The Utah Seven Telescope Array has been constructed at Cedar Mountain (1 600 m a.s.l.), Dugway in Utah (40.33° N, 113.02° W) [2]. Each telescope is arranged at the grid of a regular hexagon and at the center with a separation of 70 m. We have started the operation with three telescopes since March, 1997.

Each telescope has a 3 m diameter dish which consists of nineteen hexagonal segment mirrors with a total effective mirror area of 6 m^2. The 256 channel cameras with 0.25 degree pixels are mounted on the focal plane. This camera is made of multianode photomultipliers (MAPMT) having 4 pixels.

The threshold level of discriminator in each channel corresponds to five photo-electrons. We require four hit channels for triggering the events. The resultant event rate in each telescope was about $4 \sim 5$ Hz.

A tracking method called raster scan is employed for our observation. During the scan the center of the field of view scans the square region of $0.5° \times 0.5°$ in right ascension and the declination coordinate centered on the target. The absolute direction of the objects is calibrated using bright star measurements.

3. Analysis

In order to determine the relation between the primary energy and the shower parameters, photon intensity, core distance, and zenith angle, we have generated showers using the simulation code CORSICA.

The simulation includes the effect of scattering process in the atmosphere, mirror shapes, the dead space between the segment mirrors, the shadows by PMT camera cluster and its support, the night sky background noise, Q.E. response curve of the MAPMT and so on. ADC counts of each channel are calculated using 5 ADC counts = 1 photoelectron.

From shower images on the cameras of multiple telescopes, image parameters are calculated and a shower axis is obtained. A detector-shower plane which includes the position of the telescope and the shower axis is determined for each telescope. Then we can determine the intersection line of these planes, which corresponds to the three-dimensional shower axis. Core location of the shower is determined as the intersection point of the shower axis and the ground plane. The position resolution obtained by this method is 12 m in which 50% of the total events are included (Fig. 1).

The relation between the total ADC counts and the primary energy of gamma rays is estimated as a function of zenith angle and core location. Based on this relation, the primary energy of gamma rays is determined event by event. The energy resolution obtained from this analysis is 23%.

Based on the above simulation, we tried to obtain the differential energy spectrum of the gamma-ray

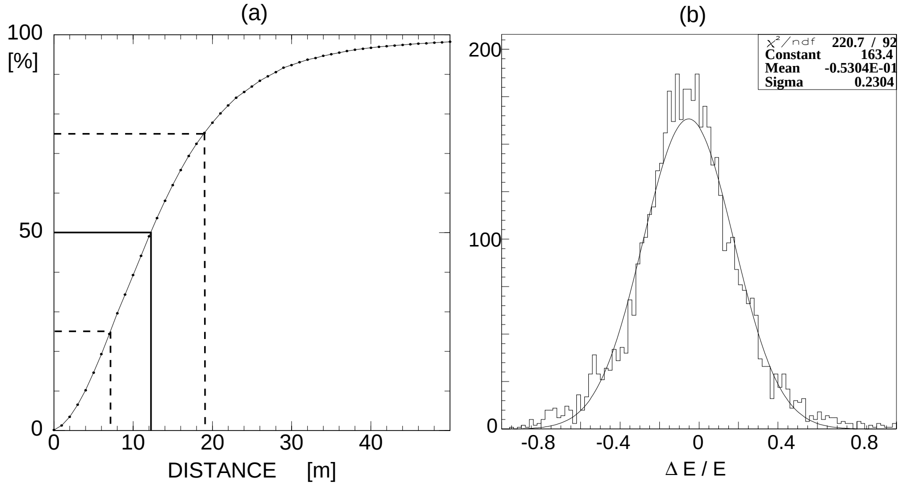

Fig. 1. (a) Position resolution of the core location for gamma rays estimated by the simulation. The percentage of the estimated core locations integrated from the true position of the air showers is shown. (b) Energy resolution obtained by the simulation.

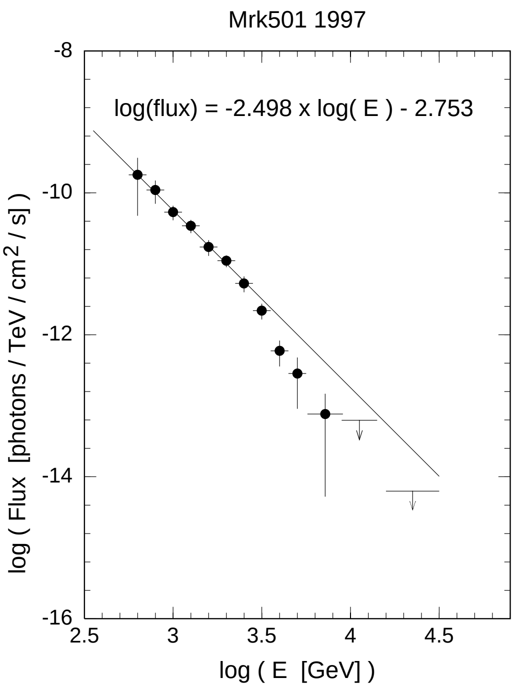

Fig. 2. Differential energy spectrum of the gamma rays from Mrk501 obtained by the stereoscopic analysis.

flare from Mrk501 using the data acquired from the beginning of April to the end of the July 1997. During this period, three telescopes were operated. The total observation time was 137.6 hours. We calculate the energy distributions in the on-source and in the off-source region, respectively. Subtracting off-source events from on-source events, the energy distribution of the gamma rays is obtained. Taking into account the effective area and the observation time, the differential energy spectrum of the gamma rays from Mrk501 is calculated (Fig. 2).

4. Conclusion

We have developed a method of energy determination for gamma rays using a stereoscopic technique. The position resolution obtained of the core location is 12 m, and the energy resolution is 23%. Note that the image parameters like WIDTH and LENGTH are not used except to determine the image axis in this analysis. We have obtained the differential energy spectrum of the gamma-ray flare of Mrk501 in 1997. The flux of the gamma rays is well represented by a differential power spectrum with an index of -2.5 between 700 GeV and 3 TeV and the steepening effect seems to appear above several TeV [3–5].

The Utah Seven Telescope Array is powerful, especially for accurate measurement of TeV gamma-ray energies.

Acknowledgements

The authors would like to thank the HiRes group and people at Dugway for help with observations. This project is supported by the Grants-in-Aid for Scientific Research by MONBUSHOU and is also partly supported by the Science Research Promotion Fund of the Promotion and Mutual Aid Corporation for Private Schools of Japan.

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