ICRC'07
Mérida, México

Study on TeV γ Ray Emission from Cygnus Region Using the Tibet Air Shower

THE TIBET ASγ COLLABORATION

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Abstract: Using data taken from Tibet III air shower array between November of 1999 and November of 2005, we analysis the γ ray emission from Cygnus Region. A 5.8 standard deviation(σ) excess is found to peak at R.A.$\sim 304°$ and Dec $\sim 36°$N, close to the MILAGRO newly reported source MGRO J2019+37, and consistent with γ ray emission from an extended source. Preliminary results on the spectrum of the MILAGRO source in the Galactic plane are obtained.

Introduction

The Cygnus region of the Galactic plane is rich in candidate Galactic cosmic rays sources and complex features are revealed in broad wavelength bands of radio, infrared, x-rays and γ rays. The first detailed views of the diffuse γ ray emission from this region can be traced back to the time of SAS2 and COSB [1] satellite experiments. It was until the notable observation made by EGRET [2] on board of Compton Gamma Ray Observatory, that Cygnus region became known as the brightest diffuse gamma ray emission source in the entire northern hemisphere. Serendipitous discovery of an unidentified TeV gamma ray source J2032+4130, made by HEGRA [3] with archive data originally devoted to Cyg X-3, was the first positive detection of TeV emission from this region. In the mean while, owing to the wide field of view capability, ASγ and MILAGRO performed all sky survey at TeV energy range and both found marginal event excess (about 4 σ) close to the direction of R.A.$\sim 305°$ and Dec $\sim 37°$N [4, 5]. The spatial coincidence from two independent observations leaded to the conclusion that one or more new unidentified TeV γ ray sources should be very likely to exist in this region and more sensitive observation was demanded [6]. With moderate discrimination power between γ ray and cosmic ray background, MILAGRO reported the first positive TeV diffuse γ ray emission from the Galactic plane [7] and the discovery of TeV γ ray source MGRO J2019+37 recently [8]. Tibet air shower array also reported an excess of TeV cosmic ray flux from Cygnus region. The compactness of the excess favors the interpretation that the extended γ-ray emission from the Cygnus region makes considerable contribution [9].

In MILAGRO's work, the γ-ray flux is only measured for one energy point (12TeV), and is found to be significantly higher than the expectation from the conventional model. To measure the energy spectrum is therefore very useful in understanding the emission mechanism in this region. With successful measurement of the energy spectrum of γ-ray emission from Crab [10], Mrk501 [11] and Mrk421 [12], this work attempts to determine the energy spectrum of MGRO J2019+37.

Tibet Air Shower Array

The Tibet air shower array experiment has been sucessfully conducted at Yangbajing(90.522°E, 30.102°N) in Tibet, China, Since 1990 [13], at an altitude of 4300m above sea level. The experiment was gradually enlarged and upgraded to current scale (Tibet III array) by increasing the number of detectors from Tibet I and Tibet II array. The Tibet III array [14], used in this analysis, was completed in the late fall of 1999, which covers an area of 22,050 m^2 and consists of 533 scintillation detectors of 0.5 m^2. The Tibet III array has a mode energy of about 3 TeV and trigger rate of about 680 Hz. Based on moon shadow analysis, the array was estimated to have an angular resolution of 0.9° from Monte Carlo(MC) simulations.

The events are selected by imposing four criteria on the reconstructed data set obtained by running the Tibet III array in 1318.9 days between November of 1999 and November of 2005: (1) Each shower event should fire four or more FT detectors recording 1.25 or more particles. (2) The estimated shower center location should be inside the array. (3) The sum of the number of particles per m^2 detected in each detector $\sum \rho FT$ should be larger than 15. (4) The zenith angle of the incident direction should be smaller than 40°. After all data quality cuts, about 1.8×10^{10} shower events were available for analysis.

Data analysis and Results

The all-distant "equi-zenith angle" method described in [4] was firstly used to produce the two dimensional (2D) cosmic ray intensity map. In brief, for each short time step (e.g., 1 min interval), the relative cosmic ray intensities at points in every equi-zenith angle belt are obtained by comparing the number of observed events, and this comparison can be extended step by step to all points in the surveyed sky. To remove the large scale cosmic ray anisotropy and to keep the local event excess structure which is due to the γ ray emission, the similar subtraction procedure as used in [4] is adopted, except that the "on" source window and its neighbouring space (10° around the extended source search) are excluded when parameterizing

the projected intensity distribution along R.A. direction for any Dec belt. With the map of this intensity and number of observed events, the background event map and therefore the significance map can be derived:

$$N_b(R.A., Dec) = \frac{N_s(R.A., Dec)}{I(R.A., Dec)} \quad (1)$$

$$\sigma(R.A., Dec) = \frac{N_s(R.A., Dec) - N_b(R.A., Dec)}{\sqrt{N_s(R.A., Dec)}} \quad (2)$$

Where $N_s(R.A., Dec)$, $N_b(R.A., Dec)$ and $I(R.A., Dec)$ are the number of events in an on-source bin, the average number of events in its corresponding off-source bin and the relative intensity respectively. Fig.1 a) shows the significance distribution for all points in the survey sky, it agrees with a normal distribution very well in the negative side, which indicates that the systematic effects are under well control. The positive side contains more entries than what is expected from a pure statistic fluctuation, and we find it attributes to the event excess from directions of Crab, Mrk421, as well as Cygnus region. After removing their contributions, in such a way that those cells within $2°$ around Crab and Mrk421 and those cells within $10°$ around MGRO J2019+37 are excluded,we get the dot-dashed histogram as shown in Fig.1 a). We can see the significance distribution from the rest of the cells, agree much better with a normal distribution. Fig.1 b) shows the 2D significance map containing Cygnus region and the Galactic plane we are interested in. The highest significance value is found to be 5.8 σ locating at $(304°, 36.1°)$, consistent with the location of MGRO J2019+37 considering the pointing error from both experiments. There are other three bright zones located at $(307.1°, 41.7°)$, $(311.6°, 36.7°)$ and $(318.8°, 40.5°)$, with significance of 3.83σ, 4.49σ and 4.07σ respectively. And a few more directions show event excess which indicates the possible diffuse γ ray emission.

To measure the energy spectrum, the overall selected event sample is further divided into 4 subsets according to $\sum \rho FT$, an observable variable proportional to the primary energy: $15 \leq \sum \rho FT < 27$, $27 \leq \sum \rho FT < 47$, $47 \leq \sum \rho FT < 178$, $178 \leq \sum \rho FT < 1000$, with which number of excess events can be obtained for
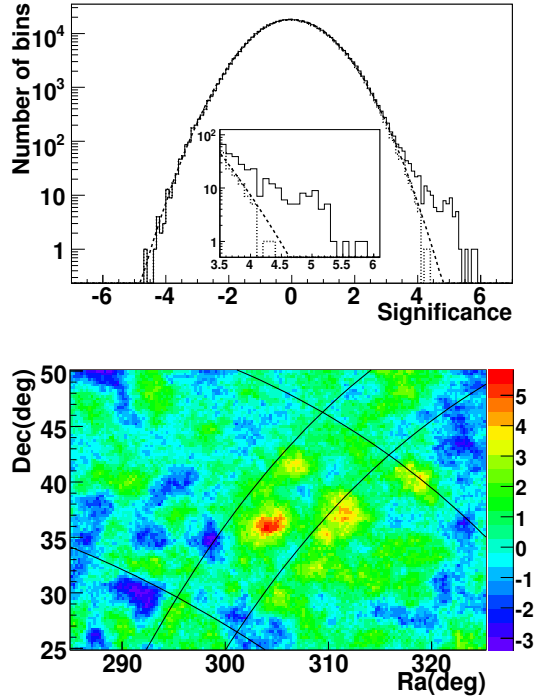

Figure 1: Significance map. In a) The solid line is derived from all cells defined in the analysis. The dot-dashed histogram excludes cells close to Crab or Mrk421 and excludes cells in Cygnus region. The dashed line represents the best Gaussian fit to the data. In b) Four thin curves stand for the Galactic latitude b=$\pm 3°$ and longitude $l = 65°, l = 85°$.

each sample accordingly. To account for the detector response, i.e., the energy dependent effective area of the objects we are observing, fully simulated MC samples are generated. We use CORSIKA version6200 code for the generation of air shower events and the EPICSUV7.24 for detector simulation. We assume a power law spectrum with spectral index varying from -2.0 to -3.0 attempting to find the best fit to the experimental data. The diurnal motion of the objects are properly taken into account and the air shower events are uniformly thrown within a circle with a radius of 300m centered at the core of our array. Using the number of excess events of each $\sum \rho FT$ bin from MGRO J2019+37, detector livetime for the observations, simulated effective area,

and the correlation between $\sum \rho FT$ and primary γ-ray energy, We can get the differential γ-ray flux as shown in Fig.2. The energy points are defined as the mean logarithmic energy of the data set. By

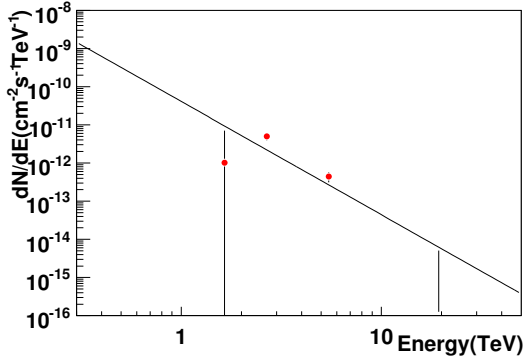
Figure 2: Differential flux of MGRO J2019+37 with Tibet III data.

fitting the data in the energy range between 0.3 and 50TeV using a simple power law spectrum $dN/dE \propto \alpha E^{-\beta}$ (cm^{-2} s^{-1} TeV^{-1}), we yield: $\alpha = (4.10 \pm 0.85) \times 10^{-11}$; $\beta = -2.97 \pm 0.33$. We can see the first point on the low-energy side and the last point on the high-energy side don't agree well with the fitted result.To estimate the systematic error of the energy spectrum, we consider several factors such as the smooth radius, the size of the excluded region when performing large scale anisotropy subtraction and the source position. After all, the systematic uncertainty is 1.1×10^{-11} for α and 0.45 for β .

As for the diffuse emission from rest of Cygnus region, the statistical significance is lower(about 3σ) and we can't get accurate energy spectrum. With the data accumulating, we will analysis it in future.

Conclusions and Discussion

Using the Tibet III array data set obtained in 1318.9 days between November of 1999 and November of 2005, we found the highest significant excess is 5.8 σ and located at $(304°,36.1°)$. Preliminary energy spectrum of the MILAGRO source J2019+37 measured to be $dN/dE = (4.10 \pm 0.85_{stat} \pm 1.1_{sys}) \times 10^{-11} E^{-2.97 \pm 0.33_{stat} \pm 0.45_{sys}} cm^{-2} s^{-1} TeV^{-1}$.

More studies on systematic uncertainty are undergoing.

Acknowledgements

References

[1] R. C. Hartman, D. A. Kniffen, et al. *ApJ*, 230: 597-606,June 1979.

[2] S. D. Hunter, D. L. Bertsch, et al. *ApJ*, 481:205+, May 1997.

[3] F. Aharonian, A. Akhperjanian, et al. *A&A*, 393:L37-L40, October 2002.

[4] M. Amenomori, S. Ayabe, et al. *ApJ*, 633:1005-1012, November 2005.

[5] R. Atkins, W. Benbow, et al. *ApJ*, 608:680-685, June 2004.

[6] G. Walker, R. Atkins, and D. Kieda. *ApJ*, 614:L93-L96, October 2004

[7] R. Atkins, W. Benbow, et al. *Phys. Rev. Lett.*, 95(25):251103+, December 2005.

[8] A. A. Abdo, B. Allen, et al. *ApJ*, 658:L33-L36, March 2007.

[9] M. Amenomori, S. Ayabe, et al. *Science*, 314:439-443, October 2006.

[10] M. Amenomori, S. Ayabe, et al. *ApJ*, 525:L93-L96, November 1999.

[11] M. Amenomori, S. Ayabe, et al. *ApJ*, 532:302-307,March 2000.

[12] M. Amenomori, S. Ayabe, et al. *ApJ*, 598:242-249, November 2003.

[13] M. Amenomori, Z. Cao, et al. *Phys. Rev. Lett.*, 69:2468-2471, October 1992.

[14] M. Amenomori, S. Ayabe, et al. *ICRC*. 2:573+, 2001.