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Two dimensional observation on TeV Cosmic-ray large scale anisotropy using the Tibet Air Shower Array

The Tibet ASγ Collaboration
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The two-dimensional large scale anisotropy of cosmic-ray intensity in a magnitude about 0.1% is observed in TeV energy range using data taken from Tibet-III (Nov.1999-Oct.2003). The anisotropy due to the terrestrial orbital motion around sun is discussed simultaneously.

1. Introduction

The study of the anisotropy of galactic cosmic-ray intensity is an essential tool, as it is expected to carry important information about the origin and the propagation mechanism of the galactic cosmic-rays. There are several processes that can lead to the cosmic-ray anisotropy. One process based on the reliable theory is the Compton-Getting (C-G) effect [1], which is due to an observer's motion with respect to a locally isotropic distribution of cosmic-rays. When an observer moves with respect to the rest frame of the cosmic-ray plasma, the fractional intensity enhancement due to the C-G anisotropy is expressed as as Eq. (1)

$$\frac{\Delta I}{< I >} = (\gamma + 2)\,\frac{v}{c}\,\cos\theta\ , \tag{1}$$

Here I denoting the cosmic-ray intensity, γ the power-law index of the cosmic-ray energy spectrum, v/c the ratio of the detector's velocity to the speed of light, and θ the angle between the arrival direction of cosmic rays and the direction of detector motion. One possible C-G effect might result from solar motion with respect to galactic center, which can be measured in the sidereal time. Adopting the parameters of $\gamma = 2.7$ and v=220km/s toward $l = 90^o$, $b = 0^\circ$ for this motion, $\Delta I/I = 0.34\%$. The other C-G effect due to the earth's revolution around the sun can be measured in solar time. Ignoring the earth's orbital eccentricity, the C-G modulation due to this orbital motion peaks near 6am in local solar time, with amplitude at 0.05% or less, depending on the geographic latitude of experimental site. This kind of C-G effect has been reported in our paper [2]. Here we presented the preliminary result on two-dimensional sidereal time anisotropy with Tibet III data analyzed by the method based on equi-zenith method[3]. The one-dimensional anisotropy has been reported in our previous paper [4].

2. Observatory

The Tibet air shower experiment has been operated at Yangbajing (90.53°E, 30.11°N; 4,300m a.s.l.) in Tibet, China since 1990. After about fourteen years' operation, it has been developed from the Tibet-I and Tibet-II/HD to Tibet-III array. Tibet III array, used in the present analysis, was completed in the late fall of 1999,which consists of 533 scintillation counters of 0.5 m^2 each placed on a 7.5 m square grid with an enclosed area of 22,050 m^2 and each viewed by a fast-timing (FT) photo-multiplier tube. In the late fall of 2003, the area of the Tibet III array was further enlarged up to 36,900 m^2 by adding 256 counters. A 0.5 cm thick lead plate is put on the top of each counter in order to increase the array sensitivity by converting γ rays into electron-positron pairs. The angular resolution of the Tibet III is about 0.9° in the energy region above 3 TeV, as estimated from full Monte Carlo (MC) simulation and verified by the moon shadow measurement from observational data. The trigger rate is on average about 1200 Hz for the Tibet III. In this work, after imposing strict data selection criteria [3], data sample includes 1.36×10^{10} events between 918 live days' running of Tibet-III array from Nov. 1999 to Nov. 2003.

3. Analysis

Because the Tibet air shower array can not distinguish a γ-ray induced shower event from the overwhelming CR background shower events, when tracing and counting the number of events in an "on-source window" centered at a candidate point source direction with a size at the level of angular resolution, the number of background events must be estimated from the observational data recorded in the side band, which is usually referred to as "off-source window".

Sitting on an almost horizontal plane, the Tibet III array has almost azimuth-independent efficiency in receiving the shower events for any given zenith angle. The equi-zenith angle method was therefore developed. In brief, simultaneously collected shower events in the same zenith angle belt can be used to construct the "off-source windows" and to estimate the background for a candidate point source located in the same zenith angle. This method can eliminate various detecting effects caused by instrumental and environmental variations, such as changes in pressure and temperature which are hard to be controlled and intend to introduce systematic error in measurement. The celestial space from 0° to 360° in R.A. and from -10° to 70° in Decl. are binned into cells with a bin size of 2° in both the R.A. and Decl. directions. In the observer's coordinates, the zenith angle θ is divided from 0° to 40° by a step size of 1°, and the azimuth angle ϕ is binned by a zenith angle dependent bin width (1°/ sin(θ)). For every local sidereal time (LST) interval bin (8min) m, a cell in (θ, ϕ) space (n, l) is mapped to a celestial cell $(\alpha_i,\ \delta_j)$, i.e. R.A. bin i and Decl. bin j, through two discrete coordinate transformation functions $\imath(m, n, l)$ and $\jmath(m, n, l)$. Therefore, at a certain LST bin m, the number of events accumulated in zenith angle bin n and azimuth angle bin l is directly related to the CR intensity $I(i, j)$ in cell (i, j) of celestial space. Denoting the number of observed events after azimuth angle correction as $N_{\mathrm{OBS}}(m, n, l)$, and the relative intensity of CR as I(i,j), the equi-zenith angle condition leads to the following χ^2 function: Eq. (2)

$$\chi^2 = \sum_{m,n,l} \frac{\left[N_{\mathrm{OBS}}(m,\, n,\, l) \Big/ I(i,\, j) \;-\; \sum_{l' \neq l} \Big(N_{\mathrm{OBS}}(m,\, n,\, l') \;/\; I(i',\, j') \Big) \Big/ \sum_{l' \neq l} 1 \right]^2}{N_{\mathrm{OBS}}(m,\, n,\, l) \Big/ I^2(i,\, j) \;+\; \sum_{l' \neq l} \Big(N_{\mathrm{OBS}}(m,\, n,\, l') \;/\; I^2(i',\, j') \Big) \Big/ \big(\sum_{l' \neq l} 1\big)^2} \tag{2}$$

Here, (i, j) is mapped from (m, n, l) by the above-mentioned transformation functions. I(i,j) can be calculated by minimizing this χ^2 function. Detail of this method can be found in our paper[3].

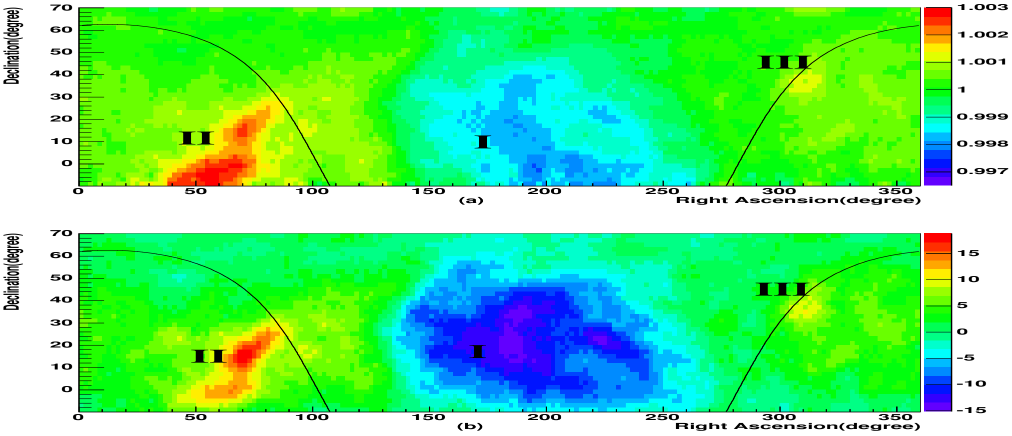

Figure 1. (a) Map of relative intensity in equatorial coordinate. (b) Significance map of excess or deficit events. Events within a radius of 5° are summed up in each bin. To guide the eye, solid line indicates position of Galactic Plane.

4. Results and Conclusions

Fig. 1 (a) shows the map of the relative cosmic-ray intensity in equatorial coordinate system. The significance of the relative cosmic-ray intensity deviating from an isotropic one is plotted in Fig. 1 (b). Three regions

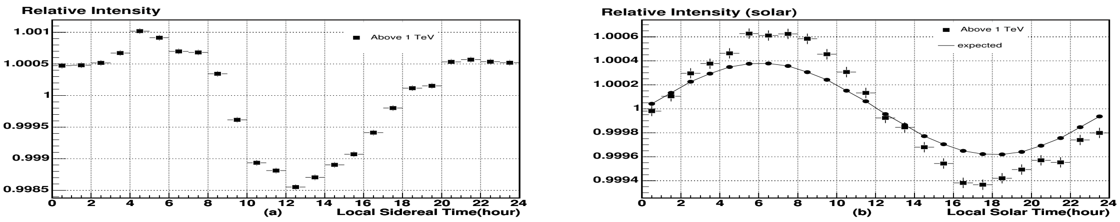

Figure 2. (a) Projection of the large scale anisotropy in local sidereal time along the R.A. direction above 1 TeV; (b) Average solar daily variation in the data above 1 TeV. The expected variation due to the C-G effect is shown in solid line.

are distinguished from the rest part of the map. In Region I, a large area around 180° in right ascension and extending from $-10°$ to 50° in declination, a significant deficit in intensity is observed. In region II, extending from 40° to 80° in right ascension and from $-10°$ to 30° in declination, an excess in intensity with 15σ can be found. This is qualitatively consistent with the anisotropy component first found in the sub-TeV region by underground muon detector and named "Tail-In" anisotropy [5]. The third interesting region is from Cygnus arm, which is around 310° in right ascension and 40° in declination. In this region, evidences for both TeV γ-ray point source and extended γ-ray emission [6] have been reported. On our map, cosmic-ray intensity in this region is significantly enhanced, but unfortunately, this work is not able to tell how much it is coming from γ-rays. By projecting the anisotropy along right ascension direction, Fig. 2 (a) shows the one-dimensional anisotropy. This is consistent with the sidereal time daily variation reported in our paper[4]. As in local sidereal time, similar procedure is employed in local solar time. Fig. 2 (b) shows the average solar daily variation observed by Tibet III. The solid line in the plot is the expected variation due to the C-G anisotropy. Note that the experimental measurement disagrees with the theoretical calculation. An additional diurnal anisotropy is superposed in local solar time, probably due to the solar modulation. Same phenomenon obtained by another method has been reported in paper [2].

In conclusion, preliminary result on two-dimensional cosmic-ray intensity has been obtained using Tibet III data. A large scale anisotropy of the cosmic-ray intensity in a magnitude of 0.1% has been observed. One-dimensional anisotropy in local sidereal time and in local solar time are both obtained.

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References

[1] A. H. Compton and I. A. Getting, Phy. Rev. 47, 817(1935)
[2] M. Amenomori et al. Phy. Rev. Lett. 93 (2004) 061101.
[3] M. Amenomori et al. astro-ph/0502039.
[4] M. Amenomori et al. 2005, ApJ, 626, L29.
[5] Hall, D.L. et al. 1999, J. Geophys. Res., 104, 6737
[6] Saz Parkinson, P. M. astro-ph/0505335