Galactic anisotropy of multi-TeV cosmic-ray intensity observed by the Tibet III air shower array

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] K. Munakata,[15] H. Nanjo,[1] M. Nishizawa,[16] M. Ohnishi,[13] I. Ohta,[9] T. Ouchi,[13] S. Ozawa,[9] J.R. Ren,[3] T. Saito,[17] M. Sakata,[10] T. Sasaki,[8] M. Shibata,[12] A. Shiomi,[13] T. Shirai,[8] H. Sugimoto,[18] K. Taira,[18] 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] X.C. Yang,[7] Y. Yamamoto,[10] Z.H. Ye,[14] G.C. Yu,[6] A.F. Yuan,[6] 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]
(Tibet ASγ Collaboration)
(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) Department of Physics, Shinshu Univ., Matsumoto, Japan, (16) NII, Tokyo, Japan, (17) Tokyo Metropolitan Coll. of Aeronautical Eng., Tokyo, Japan, (18) Shonan Inst. of Technology, Fujisawa, Japan

Abstract

We have been observing multi-TeV cosmic rays by the Tibet III air shower array since November 1999. This continuous observation enables us a detailed analysis of the sidereal and solar daily variations of the galactic cosmic-ray intensity. The observed solar daily variation is compared with the expected variation that includes the Compton-Getting effect due to the revolution motion of the earth around the sun. The variation in the higher-energy event samples (log mean energy 6.7 TeV) is consistent with the expected anisotropy, while the variation in the lower-energy event samples (log mean energy 3.8 TeV) suggests an additional diurnal anisotropy superposed, probably due to the solar modulation. This is the highest-precision measurement of the Compton-Getting anisotropy ever made.

1. Introduction

The galactic anisotropy of the cosmic-ray intensity is expected to carry information about the origin and the propagation mechanism of galactic cosmic rays, as it reflects the galacticmagnetic field through which they have passed

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and their energy spectrum at source. The average amplitude of the anisotropy is very small (0.1% or less). Especially, at the multi-TeV energy region there are few observational results and it is presumed that the anisotropy at multi-TeV energies is almost free from heliospheric disturbance. If it is true, the Compton-Getting effect [1] (the cosmic-ray anisotropy due to the terrestrial orbital motion) should be energy-independent.

Cutler and Groom [2] showed the first clear evidence for the Compton-Getting effect at 1.5 TeV in 1986. Their result was in reasonable agreement with the sine curve, however, the peak of the curve shifted from the expected (6:00 LT) by +2 hours at 2σ significance and they claimed that it was caused by the meteorological effect. We will report on the Compton-Getting effect observed in the solar time by the Tibet air shower array (Tibet III). Analysis in the sidereal time is under way.

2. Analysis

The Tibet III air shower array (90.52°E, 30.10°N, 4,300m above sea level) has been in operation since November 1999 at a trigger rate of 680Hz with energy threshold of a few TeV. The angular resolution of the Tibet III is estimated to be 0.9° at a few TeV. The details of the detector is found elsewhere [3]. According to our standard air shower event criteria, we selected 10^{10} events recorded during a period between November 1999 and October 2001.

The data samples subsequently histogrammed in hourly bins based on the solar time (365 cycle/year), according to each event time, direction and estimated primary energy. In consideration of seasonal change in the solar daily variation, the analyzed data are divided monthly and corrected for the observation time.

Then, to discuss the daily variations with small amplitude (0.05% or less), we adopted the East − West subtraction method that divide the air shower data into 'East' and 'West' (E- and W-) groups according to the geographical longitude of the incident direction of each shower at each hourly bin and subtracts the variations in number of events in the W- group from those in the E- group. (Details of this method are described in [4]) Since the number of events in the E- and W-groups are not necessarily the same, because of the experimental conditions, the subtraction should be performed after converting the number of event into the deviation in unit of % from the mean in each group. This method cancels out the meteorological effect and the possible detector biases which is expected to produce the common variation in both groups. We confirmed that this subtraction method is consistent with the traditional correction techniques using the atmospheric pressure and temperature data. Figure 1. shows the average subtraction in the solar (left) and anti-sidereal (right) times. The insignificant variation in the anti-sidereal time (364 c/y) ensures that the seasonal change of the solar daily variation is small.

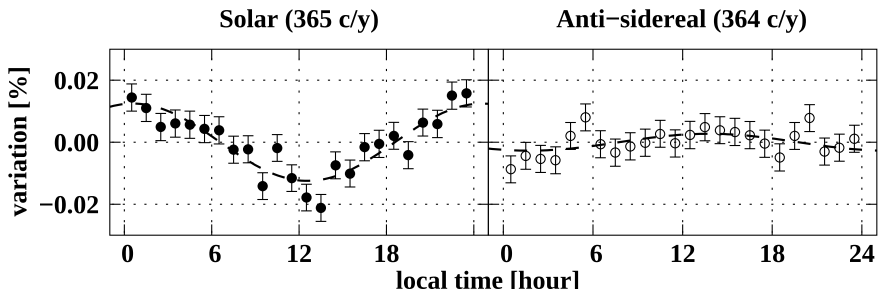

Fig. 1. The differential form of average daily variations in the local solar (left) and anti-sidereal (right) time frames, based on all the data. Broken lines show the χ^2-fitted sine curves which have 0.012±0.0013% and 0.0027±0.0013% amplitude respectively.

A possible drawback of this method is that the measured results give the "differential" form of the variations, that is, actual physical variations are reconstructed by "integrating" the subtracted variation. This makes the error estimation difficult. Hereafter, our statistical argument is made based on the "differential" form and the physical anisotropies are expressed by the integral of the fitting curve of the differential form in this paper. Note that this way to interpretation is valid only when the fitting curve is cyclic, like a trigonometric function.

On the other hand, the expected anisotropy is calculated by assuming a power-law cosmic-ray flux with spectral index of -2.7 and the Compton-Getting effect at our site. The expected curve is obtained by considering the effective area of Tibet III.

3. Results and Discussion

Figure 2. shows the solar daily variation observed by Tibet III together with χ^2-fitting results. It should be noted that the peaks shifted from the prediction of the Compton-Getting effect by about 6 hours (1/4 cycles) and the amplitude is multiplied by a factor $\pi/12$ in the upper panel, because the histograms express the differential form of the actual solar daily variation.

The fitting results of the divided data are summarized in Table.1. The higher-energy data (6.7 TeV) are consistent with the expected within statistics, however, the lower-energy data (3.8 TeV) deviate from the expected at 4σ significance in phase and at 5σ significance in amplitude.

log mean	amplitude $\times 10^{-3}$[%]		phase (from 6:00LT) [min]	
energy	CG	χ^2-fit	χ^2-fit	χ^2/d.o.f
3.8TeV	9.5	19.3±1.9	101.4±23.1	33.12/22
6.7TeV		14.4±2.4	38.0±38.4	25.1/22

Table 1. Comparison between the expected (C-G model) and the best fit to the data in amplitude and phase assuming a sine curve in the solar time. The errors in the expected amplitude and phase are negligible in the calculation.

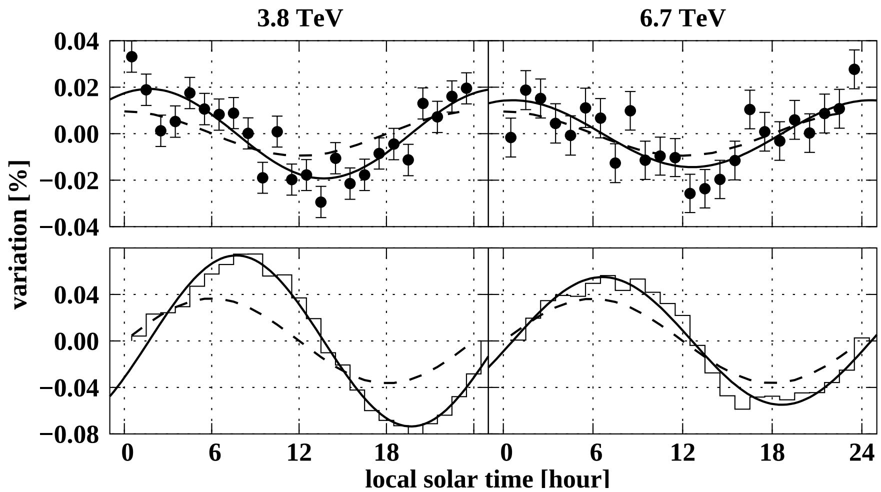

Fig. 2. Observed solar daily variations divided into energy regions compared with the expected anisotropy due to the Compton-Getting effect (the broken lines). The plot in the upper panel is the differential form of the solar daily variations, and histogram in the lower panel is physical daily variations. Solid curves are the two-parameter χ^2-fitted sine curves.

The Tibet III clearly observed the Compton-Getting effect around 6.7 TeV, and suggests possible existence of some other effects, probably the solar modulation, around 3.8 TeV. Extensive study of systematic errors is under way. If this effect is caused by the solar modulation, the deviation of the observed variation from the Compton-Getting anisotropy should vary in the solar activity cycle. The data we currently have cover only the solar maximum period, we can examine this hypothesis by continuing the observation for a full solar cycle of the solar activity. Furthermore, it may be very useful to lower the energy threshold down to sub-TeV by upgrading Tibet III, in order to better understanding the phenomenon.

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