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Sidereal Daily Variation of ~10 TeV Cosmic-ray Intensity Observed by the Tibet Air-shower Arrays

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Abstract

We analyze the sidereal daily variation of galactic cosmic-ray intensity observed by the Tibet-I air-shower (AS) array in 1990-1993. To examine the declination dependence of the variation, the AS events are classified according to their incident directions. The hourly count rate is corrected for the spurious variations by taking the difference between the eastern and western count rates. We confirmed that the difference count rates are free from atmospheric effects, by analyzing data in 1992 when the atmospheric data measured at the observation site were available. The first harmonic of the daily variation obtained from the vertical count rate is consistent with the AS observations at Mt. Norikura and Baksan. We compare the resultant 24-hour profile in sidereal time with those expected from models proposed for the origin of sidereal anisotropy. We also

present the preliminary results from the high-count observation by the Tibet-II AS array which have been in operation since 1995.

1 Introduction:

Long term observations of the count rates of cosmic rays recorded by air shower arrays and underground muon telescopes have consistently reported the existence of an average diurnal variation in sidereal time (Cutler et al., 1981, Alexeenko and Navara, 1985, Nagashima et al., 1989, Cutler and Groom 1991). Most investigators have concluded that the variation is small (<0.1%) and the apparent right ascension of its maximum is somewhere in the early hours of the local sidereal day. Presently, no common consensus exists about the nature of the production mechanisms of both the LC and TI anisotropies.

Alexeenko and Navara (1985) first proposed that the sidereal daily variation is caused by the high-energy galactic diffuse gamma-rays. They showed that the variation observed by the AS experiment at Baksan is quite consistent with the variation expected from the galactic diffuse gamma-rays confined in the galactic disk. By considering the shapes of the sidereal daily variations in underground muon telescope data along with the results of the Mt. Norikura AS experiment, on the other hand, Nagashima et al. (1998) proposed that there are two anisotropic intensity distributions of high energy particles in the heliosphere. One of the anisotropies is the Loss-cone of galactic cosmic-rays (deficit in flux) and the other is an excess flux called the Tail-in anisotropy (see also Hall et al., 1999). Nagashima et al. (1998) also argued that the Tail-in anisotropy is somehow caused by the heliospheric tail, which is formed by the interaction between the solar wind plasma and the local interstellar medium. They noted that the anisotropy decreases with increasing energy above 1 TeV and almost disappear at >10TeV, a region covered by AS observations, because such energetic particles cannot be modulated in the heliospheric tail. If such energy dependence of the Tail-in anisotropy is really observed, it could give crucial evidence for the model. By analyzing the sidereal diurnal variations observed by two AS experiments at Baksan and Mt. Norikura together with those from underground muon observations, Nagashima et al. (1998) suggested that the Tail-in anisotropy decreases with increasing energy as the model predicts. These two omni-directional measurements at middle latitudes in the northern hemisphere, however, have only minor responses to the Tail-in anisotropy which is expected in Nagashima's model to have a maximum excess of intensity in the southern hemisphere. Therefore, we must wait for further examination of the energy dependence of the anisotropy in the 1-10 TeV region from southern hemisphere with sufficient response to the Tail-in anisotropy. Observation in the southern hemisphere is also very important for the test of the diffuse gamma-ray model by Alexeenko and Navara (1985), because the model predicts the variation to be out of phase in the southern hemisphere when compared with that in the northern hemisphere. In this paper, we report on the preliminary results of our analysis of the sidereal anisotropy observed by the Tibet AS array. The Tibet AS array can accurately identify the incident direction of each AS and enables us to examine the anisotropy in every latitude bin over a latitude range from 90°N up to 30°S where the Tail-in anisotropy is expected to be more significant than in the northern hemisphere.

The Tibet AS array at Yangbajing, Tibet, in China has been in operation since January 1990 (Amenomori et al., 1992, 1993). It is located at Yangbajing International Cosmic Ray Observatory (90.53°E, 30.11°N) at an altitude of 4300m (above sea level), corresponding to an atmospheric depth of 606 g/cm^2. In the present paper, we analyze the data recorded in 41 months from June 1990 to October 1993 when the array consisted of 49 scintillation detectors of 0.5 m^2 each deployed in a 7x7 matrix form with a separation of 15 m (Tibet I). The central 45 detectors in the matrix are equipped with fast response photomultipliers for the measurement of the arrival time of AS particles and the incident direction of the AS. The array was then extended in 1995 to consist of 185 detectors covering four times larger area (Tibet II).

2 Analysis and Results:

The shower events with primary energy and incident direction identified were first collected for each hour. We eliminated the influence of the non-uniform observation by including only complete hours. The average hourly count was 2.7×10^4. The shower events in each hour were classified into 6 groups (NE, NW, E, W, SE and SW) according to the geographical latitude (l) and longitude (f) of the incident direction of each shower. The hourly count in each group for a month is then binned according to its local sidereal, solar and anti-sidereal hour and the individual average count rates for each month are obtained in these three time frames. Each average hourly count rate from 41 months is then calculated, providing 24 (average) hourly values obtained from the complete set of data. We calculate the mean of these hourly values and the percentage deviation of each hourly value from the mean to obtain the average daily variations in sidereal, solar and ant-sidereal time. In this report, we eliminate the spurious variation arising from the atmospheric change and the instrumental deterioration simply by subtracting the variations in the western cells from those in the eastern cells. Through the analysis of one year data in 1992 when the atmospheric data recorded at the observation site were available, we confirmed that this subtraction is very effective method to eliminate the common variation and pick up the variation due to anisotropy which has the different phases for the eastern and western cells. Figure 1 shows the sidereal daily variations recorded in N (mean l is 60.0°N), V (29.4°N) and S (0.9°S) groups, which are respectively, reproduced from the difference variations of NE-NW, E-W and SE-SW. Also shown in the top panel is the variation in "ALL" component which is a difference between NE+E+SE and NW+W+SW. As an example of comparison with the model, we show by the thick curves the profiles expected from the diffuse gamma-rays confined in the galactic plane. We used the energy spectrum of gamma-rays given in Alexeenko and Navara (1985). The curves clearly show how the predicted variation changes with the declination. Although the observed variation in V component looks like following the predicted curve, the errors are still too large in N and S components to make a quantitative test of the declination dependence

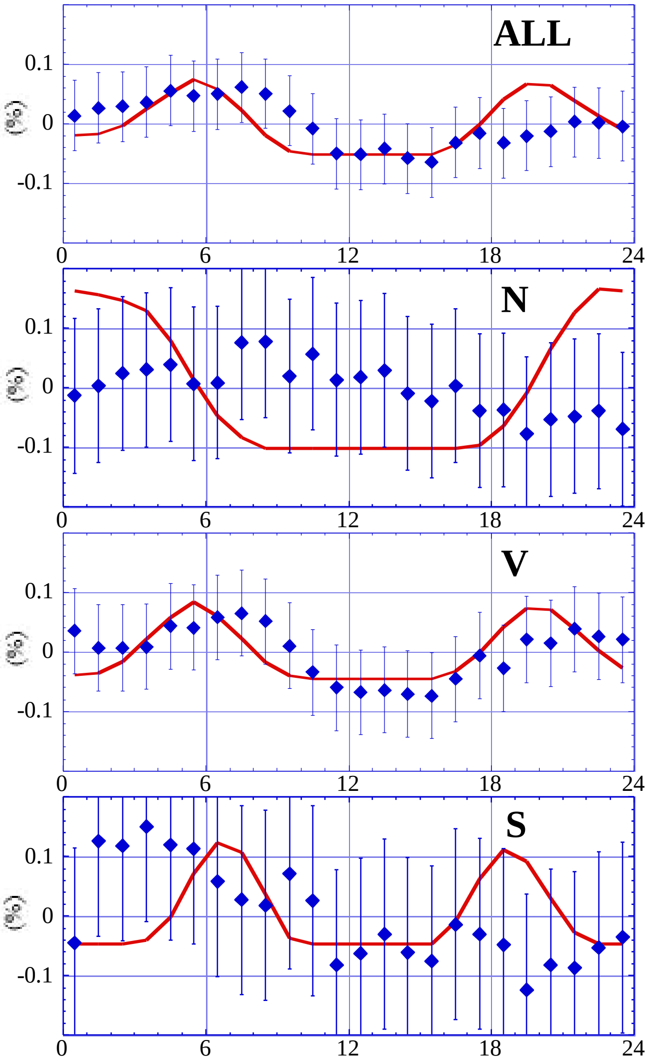

Figure 1: The sidereal daily variations recorded in three declination groups (V, N and S) of the Tibet I air-shower array during 41 months between June 1990 and October 1993. Each variation is reproduced from the difference between the eastern- and western- groups (see text).

which the model predicts. The first harmonic (diurnal term) of the variation in V component is 0.05±0.02% at 5.5±4.1 local sidereal hour (LST) and consistent with the result reported by Nagashima et al. (1989).

We next show in Figure 2 the preliminary result derived from the high-count observation with the Tibet II array. This is the sidereal daily variation in the “ALL” component averaged over 12 months between October 1995 and September 1997. The average hourly count is 2.8×10^5 (about ten times of that in Tibet I) and the errors are significantly smaller than the three years average of the Tibet I data in Figure 1. We also plotted the Norikura-3F result by the solid curve. It is seen that the agreement between these two observations is remarkable regardless of the differences in the observation period. The high-count observation with the Tibet II array may allow us to make comparisons between the observed and predicted variations in several declination bands and to test the models quantitatively.

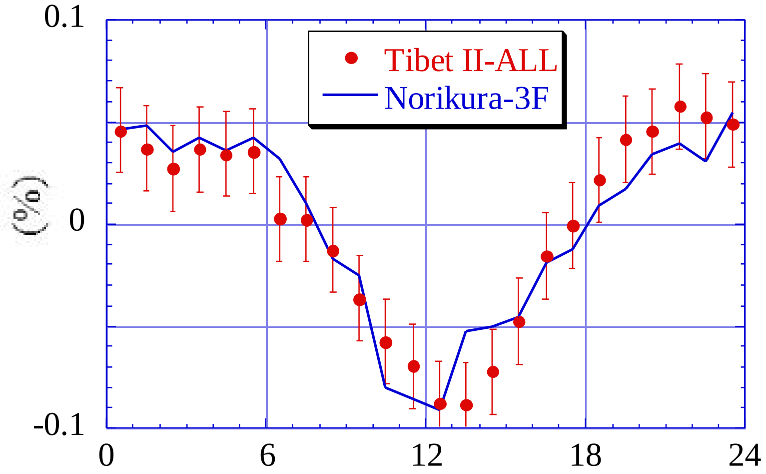

Figure 2: The sidereal daily variation recorded by the Tibet II array during 12 months between October 1995 and September 1997

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References

Alexeenko, V.V., and Navara, G., 1985, Lett. Nuovo Cimento, 42(7), 321.
Amenomori, M. et al., 1992, Physical Rev. Lett., 69, 2468.
Amenomori, M. et al., 1993, Physical Rev. D, 47, 2675.
Cutler, D.J., Bergason, H.E., Davis, J.F., and Groom, D.E., 1981, ApJ, 248, 1166.
Cutler, D.J., and Groom, D.E., 1991, ApJ, 376, 322.
Hall, D.L. et al., 1999, J. Geophys. Res., 104, A4, 6737.
Nagashima, K. et al., 1989, Nuovo Cimento, 12C(6), 695.
Nagashima, K., Fujimoto, K., and Jacklyn, R.M., 1998, J. Geophys. Res., 103, A8, 17429.