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Two-dimensional observation on TeV Cosmic-ray solar diurnal variation using the Tibet Air Shower Array

THE TIBET ASγ COLLABORATION

Abstract: The two-dimensional solar diurnal variation of the galactic cosmic-ray intensity is measured in multi-TeV energy range using data taken from Tibet air shower array (Nov.1999-Oct.2005). The variation is found to agree with the Compton-Getting effect due to the terrestrial orbital motion around the sun for the high energy event sample while additional modulation appears to exist in case of low energy. Further studies are needed in order to answer whether this is due to the solar modulation to primary cosmic rays or other effects related with cosmic rays shower.

Introduction

The study of the solar diurnal variation (SDV) of the Galactic cosmic rays (GCRs) is essential in understanding the propagation of GCRs in the galactic magnetic environment and the SDV particularly carries the information on the interaction of GCRs with helio-magnetic field [1]. D.L.Hall et al. [2] have analyzed a very long time SDV from 1957 to 1990 with rigidities between 17 to 195GV and concluded that the theoretical predictions are valid for cosmic rays up to 100s of GeV. It would be intriguing to test the GCR transporting theory with higher energy cosmic rays.

Besides the dynamic contribution, SDV has a kinetic component known as Compton-Getting (CG) effect [3], which is due to the earth's revolution around the sun. When an observer moves with respect to the rest frame of the cosmic-ray plasma, the fractional intensity enhancement due to the CG anisotropy is expressed as Eq. (1):

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

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. The CG modulation due to this orbital motion peaks near 6am in local solar time, with amplitude at 0.047% or less, depending on the geographic latitude of experimental site. Another CG effect due to the solar system rotation around the Galactic center is discussed in paper [12].

CG effect has been successfully detected by several experiments in multi-TeV energy [4, 5]. In our previous work [4], clear CG effect has been observed for high energy samples which have modal energy as 6.2TeV and 12TeV. However, the 4TeV energy sample shows extra modulation component which may come from the direct solar modulation to primary cosmic rays or from its indirect influence, such as for an example, the solar wind induced geomagnetic change may lead to a subtle diurnal variation of the air shower lateral distribution and cause in addition an apparent SDV for the "observed" cosmic rays. In latter case, the effect should not depend on the energy of primary cosmic ray but rather the number of secondary particles recorded by the EAS array. This work attempts to study this extra SDV in two dimensional (2D) picture with different energies and with different number of fired detectors.

Tibet Air Shower Array Experiment

The Tibet Air Shower Array experiment has been conducted at Yangbajing (90.522 E, 30.102 N; 4300 m above the sea level) in Tibet, China since 1990. The Tibet I array [6], consisting of 49 scintillation counters and forming a 7×7 matrix of 15 m span, was expanded to become the Tibet II array with an area of 36,900 m^2 by increasing the number of counters in 1994. In 1996, part of Tibet II with an area of 5175 m^2 was upgraded to a high-density (HD) array with a 7.5 m span. To increase the event rate, the HD array was enlarged in 1999 to cover the central part of Tibet II as Tibet III array [7, 9, 10]. The area of Tibet III array has reached 22,050 m^2.The trigger rates are $\sim$ 105Hz and $\sim$ 680Hz for the Tibet HD and III arrays, respectively. The data were acquired by the Tibet III array for 1318.9 live days from 1999.11 to 2005.10. GCR events are selected, if the air shower core position is located in the array and the zenith angle of arrival direction is less than $45°$ and any fourfold coincidence in the FT counters recording more than 0.8 particles in charge..

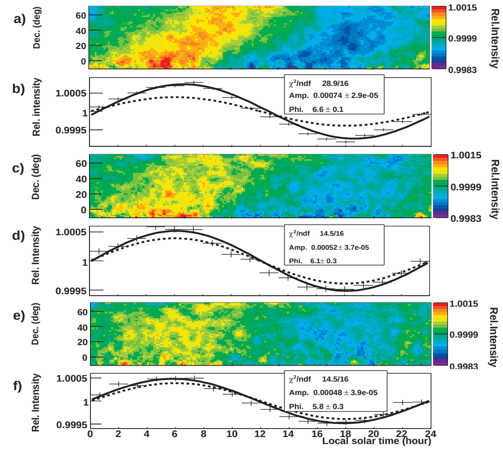

Figure 1: Cosmic ray intensity maps for Tibet ASγ data with modal energy at 4, 6.2 and 12 TeV are shown in (a), (c) and (e); In (b) , (d) and (f), the 1D plots are the projections of the 2D maps in local solar time; and the dashed lines are from the expected CG effect. The solid lines are the best harmonic fits assuming the function in the form of $\mathrm{Amp} * \cos[2\pi(\mathrm{T}-\phi)/24]$, where the local solar time T and ϕ are in unit of hour and Amp is the amplitude.

Analysis and Result

The equi-zenith angle method is used in the analysis, as the Tibet array has almost azimuth-independent efficiency in receiving the shower events for any given zenith angle. 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.

With the large statistics, we conduct a 2D measurement to reveal detailed structural information of the large-scale GCR variation beyond the simple time profiles. For each short time step (e.g. 8 minutes), the relative CR intensity at points in each zenith angle belt can be compared and this comparison can be extended step by step to all points in the surveyed sky (see Refs. [11] for details of data analysis.)

We systematically examined the CR variation in four different time frames, namely solar time for solar modulation, sidereal time for Galactic modulation, anti-sidereal time and extended-sidereal time; and systematic variations are found to be unimportant.[12]

To study the energy dependence, $\sum \rho_{\mathrm{FT}}$ variable (the sum of the number of particles per m^2 detected in each detector) is used to divide the TibetIII data into three sub-sets: [10,27), [27,47) and [47,178), each corresponds to an modal energy (the modal value of the logarithmic energy of each event by the MC simulation) of 4, 6.2 and 12 TeV as in [4]. Fig. 1 shows 2D CR intensity maps for these samples in local solar time frame. Similar to [4], the 4 TeV data sample appears to have a spurious variation with a magnitude twice that of the CG. As for the high 12 TeV data sample, the anisotropy is much more consistent with the expectation from CG effect. Besides, one can see from Fig.1 (a) that the phase of the additional modulation is not a constant but almost linearly

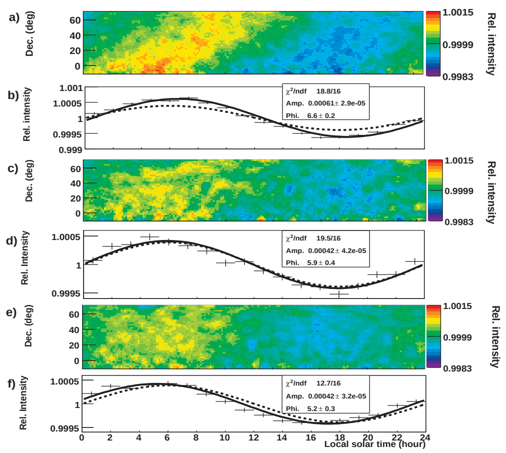

Figure 2: (a), (c) and (e) are cosmic ray intensity maps for data samples with hit multiplicity of [4,5],[6,7],[8,∞) using detector configuration of the Tibet III array. (b), (d) and (f) are the 1D projections of 2D maps in local solar time, as in Fig.1.

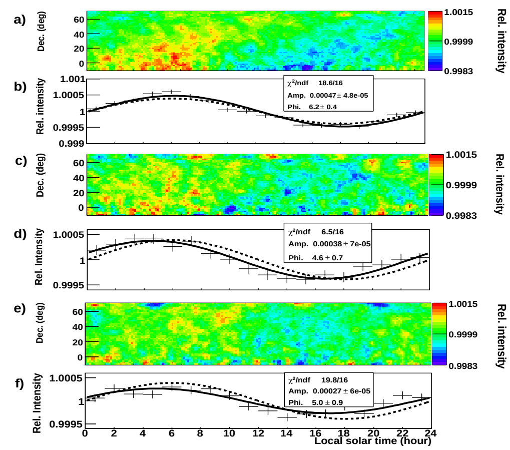

Figure 3: (a), (c) and (e) are cosmic ray intensity maps for data samples with hit multiplicity of [4,5],[6,7],[8,∞) using detector configuration of the Tibet II array. (b), (d) and (f) are the 1D projections of 2D maps in local solar time, as in Fig.1.

depends on the Declination coordination.

In our previous work [4], the trigger threshold bias has been checked and found that our detector should not be responsible to this new modulation. However, in general, many environmental parameters (e.g. geomagnetic field) have diurnal variation and have effect to the shower development differently for those come from different direction. This may effectively lead to an apparent anisotropy of cosmic rays, especially important for the threshold events, i.e., those just passing the trigger condition. [7]

To check the threshold behavior, Tibet III events are reconstructed for two different detector configurations, Tibet III and Tibet II, in latter case, only Tibet II detectors are used and a soft trigger is applied. Two configurations are expected to experience the same amount of threshold effect as they involve exactly the same process, but only scale the threshold energy.

Fig.2 shows the 2D intensity maps for data samples with different hit multiplicity utilizing detector configuration of the Tibet III array. Events with hit multiplicity [4,5],[6,7],[8,∞) are selected for three data samples respectively and the modal energies are 2.7, 5.2 and 12.5 TeV. The slope structure is significant in the low hit multiplicity sample and fades out in the high one. Similar pattern appears in the corresponding data samples with the detector configuration of the Tibet II array as shown in Fig. 3. In this case, the modal energies become larger, and are estimated as 6.7, 9.4 and 20 TeV respectively. It is interesting that Fig.3 do have similarity with Fig.2 if we only focus on the pattern of the maps which have same hit multiplicity. However, 1D projection reveals that the amplitudes of the modulation are clearly different for two different detector configuration. On the other hand, The data samples in Fig. 1 (c) and Fig. 3 (a) are almost in the same modal energy and they aslo agree with each other in both 1D and 2D distribution. This agreement tends to suggest that extra anisotropy is due to the modulation of primary cosmic ray. Nevertheless the threshold effect can not be ruled out with current analysis due to the limited statistic and energy resolution. To study the threshold effect at 12 TeV, where no extra variation should exist accoding to Fig.1(e), will be a right approach to distinguish the two possibilities.

Summary and Discussions

Preliminary result on two-dimensional cosmic-ray intensity in local solar time has been obtained using Tibet ASγ data. The solar diurnal variation in the low energy or low hit multiplicity sample consists of two components: the expected CG effect and an additional effect, in additional, the phase of the extra modulation linearly depends on the declination. Further studies are needed in order to answer whether it is due to the solar modulation to primary cosmic rays or other effects related with cosmic rays shower.

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References

[1] Parker, E.N. 1964, Planet. Space Sci., 12, 735

[2] D,L. Hall et al, ApJ, 482, 1038-1049.

[3] A. H. Compton and I. A. Getting, Phy. Rev. 47, 817(1935)

[4] M. Amenomori et al. PRL 93 (2004) 061101.

[5] D. J. Cutler, D. E. Groom, *Nature* **322**, L434 (1986).

[6] M. Amenomori *et al.*, *PRL* **69**, 2468 (1992).

[7] M. Amenomori *et al.*, *Proc. 27th ICRC*, M.Simon, E.Lorenz, M. Pohl Eds. (Copernicus Gesellschaft, 2002), **2**, pp.573-576.

[8] M. Amenomori *et al.*, *Nucl. Instrum. Methods Phys. Res.* A**288**, 619 (1990).

[9] M. Amenomori *et al.*, *PRD* **47**, 2675 (1993).

[10] M. Amenomori *et al.*, *ApJ* **598**, 242 (2003).

[11] M. Amenomori *et al.*, *ApJ* **633**, 1005 (2005).

[12] M. Amenomori et al., Science, **314** (2006) 429.