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Mean Diurnal Variations of Cosmic Ray Intensity as Measured by the Baksan Surface and Underground Detectors

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The results of measuring diurnal variations of extensive air showers (EAS) with E ≥ 100 TeV and high-energy muons with E > 220 GeV are presented. The data are obtained by the Andyrchi air shower array in 1995—2004 and by the Baksan Underground Scintillation Telescope (BUST) in the period 1982—1998. Together with previously published data on the cosmic ray anisotropy at 10 TeV obtained with the Carpet shower array at Baksan these data present three independent measurements of cosmic ray anisotropy in the energy range from 2 TeV to 100 TeV made with three different setups at one and the same place. Based on these data, the energy dependence of the amplitude and phase of the first harmonic of mean diurnal variations of cosmic ray intensity is discussed.

1. Introduction

The energy region 1-100 TeV is most suitable for investigations of the anisotropy of galactic cosmic rays, since at lower energies the effects of solar modulation distort the picture, and above this region it is difficult to have sufficient statistical accuracy in reasonable time. Within this region the measurements are made using two types of detectors: deep underground muon telescopes and surface arrays recording small-size extensive air showers. In this paper we present the results of analysis of diurnal sidereal waves in the data of two facilities of the Baksan Neutrino Observatory (the muon telescope BUST and the Andyrchi air shower array).

2. Andyrchi EAS data

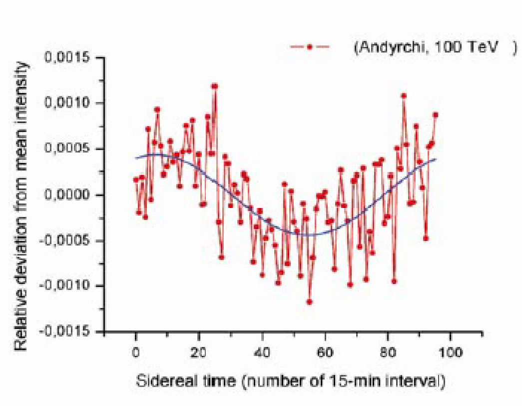

Figure 1. The sidereal diurnal wave as measure by the Andyrchi array

We have analyzed the counting rate of four-fold coincidences of any 37 detectors of the array. The database used covers the period from 1995 to 2004. The number of points analyzed during each day was 96 (15-min intervals), and the following selection criteria were used: (1) the points with deviations exceeding 3.5σ from the mean daily value were eliminated, and (2) days in which the variance of points exceeded 3.5 errors of dispersion and in which less than 66 points from 96 remained were eliminated. The total number of good days after this selection is 780 (6.108 events). The barometric coefficient is determined to be equal to -1.11% per mb, and the temperature coefficient is 0.07% per degree. After correction for pressure and temperature using these coefficients, we have determined the amplitudes and phases of daily waves of intensity in three times: solar, sidereal, and antisidereal. The effective declination of the Andyrchi array used as a wide-angle telescope is equal to 54°, though its geographical latitude is 43°. Reducing the measured amplitude of the first harmonic in solar time to zero declination, we obtained the daily wave with an amplitude of $(4.50 \pm 0.96) \cdot 10^{-4}$ and a phase of (7.18 ± 0.84) h. These values are in a reasonable agreement with $4.7 \cdot 10^{-4}$ and 6 h expected for Compton—Getting effect due to the Earth's orbital motion. The first harmonic in sidereal time has an amplitude of $(4.49 \pm 0.58) \cdot 10^{-4}$ and a phase of 1.1 ± 0.5 h. The experimental diurnal wave is shown in Fig. 1, where no serious deviation from purely sinusoidal form is seen. After reduction to $\delta_{eff} = 0°$ the amplitude of the first harmonic in sidereal time (the projection of the anisotropy vector on the equatorial plane) is equal to $(7.65 \pm 0.96) \cdot 10^{-4}$.

3. BUST muon data

The procedure of data selection is essentially the same as that describe above. The number of events detected in the period from 1982 to 1998 with a live time efficiency of 76% is equal to $5 \cdot 10^{9}$. The analysis was made for several directional telescopes selected as various combinations of the BUST planes (numeration of planes is given in [1]) and for two-fold coincidences of any planes of the BUST (the latter data sample includes all others and has the best statistical accuracy).

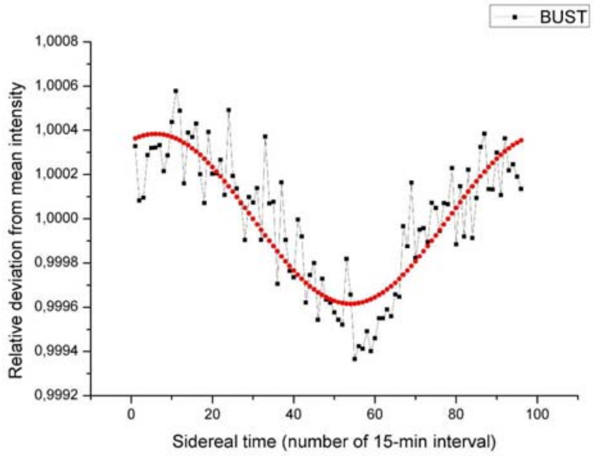

Figure 2. The sidereal diurnal wave as measured by the BUST.

The analysis was made in three times (solar, sidereal, and antisidereal). It was demonstrated previously [2, 3] that the solar daily wave is formed by the Compton—Getting effect and by positive temperature effect. The latter also makes contribution to the sidereal and antisidereal diurnal waves. The correction for temperature effect was made by the Farley-Storey method [4] using the antisidereal wave. The resulting sidereal wave for two-fold coincidences is shown in Fig. 2. All directional telescopes demonstrate consistent behavior, and the amplitudes and phases of the first harmonic in sidereal time for them, as well as their medium energies and effective declinations, are presented in Table 1. The amplitudes given in the fourth column are reduced to the equatorial plane. The amplitudes are represented as a product of the true anisotropy ξ and the cosine of its unknown declination δ_0. The fact that within statistical errors the results for all telescopes are coincident indicates to sufficient reliability of the data.

Table 1. Amplitudes and phases of sidereal diurnal waves measured by different directional telescopes of the BUST.

Telescope	Median primary energy (TeV)	δ_{eff}, deg	$\xi \cos\delta_0$ (x 10^4)	Phase (RA hours)
2 of 6 (trigger)	2.5	68	10.11 ± 0.72	1.84 ± 0.28
6-7	2.45	63	10.56 ± 1.34	1.97 ± 0.48
7-8	2.45	63	10.51 ± 1.28	2.04 ± 0.46
6-7-8	2.5	60	9.91 ± 1.50	2.04 ± 0.58
5-6-7-8	2.5	57	9.38 ± 1.52	1.89 ± 0.62
West (2-6)+(5-1)	3.2	35	11.16 ± 1.74	1.50 ± 0.60
North (5-4)+(3-6)	2.9	71	9.01 ± 1.02	1.14 ± 0.43
South (4-6)+(5-3)	5.3	23	11.89 ± 4.72	2.44 ± 1.56

4. Discussion of results and comparison with other data

The summary of world data [5-14] on the amplitudes and phases of the first harmonic in sidereal time is presented in Fig. 3.

Figure 3. Energy dependence of the amplitude (reduced to the equator) and phase of the first harmonic of

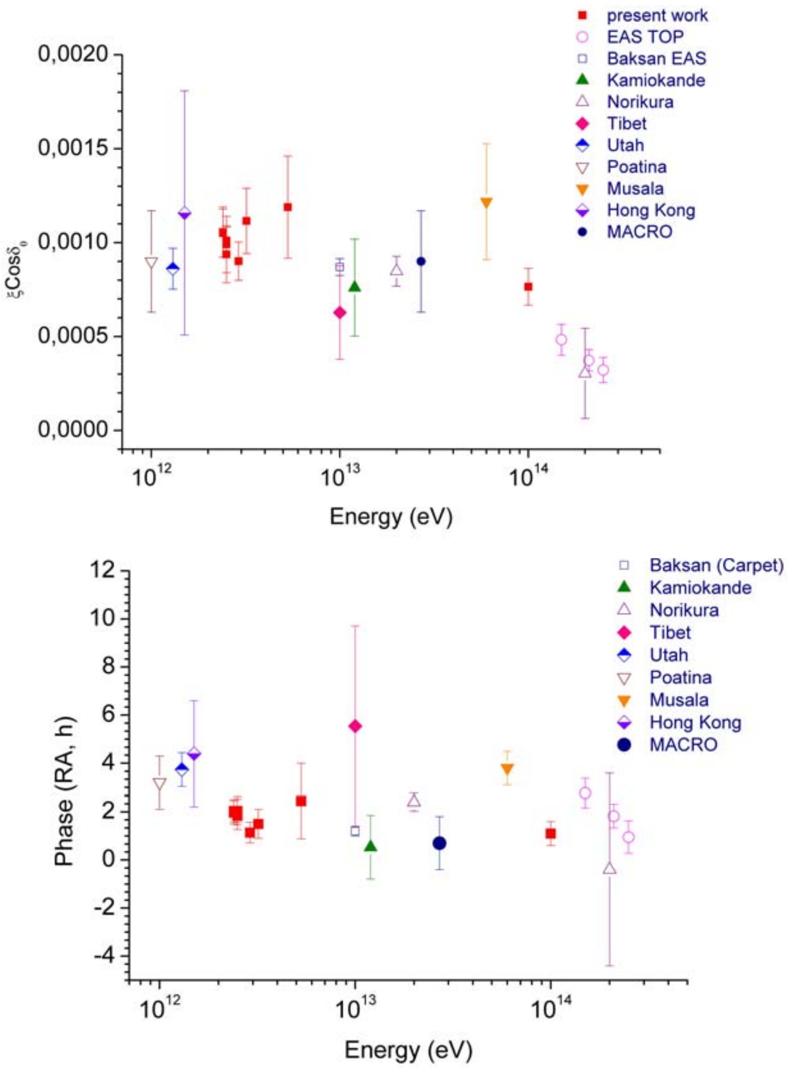

Figure 3: cosmic ray intensity in sidereal time.

Figure 3 gives the energy dependence of the projection of the anisotropy vector onto the equatorial plane. It is seen that there is a general tendency to some decrease of the amplitude of anisotropy with energy. In addition to the data presented in this paper, Fig. 3 also gives the point obtained by the third Baksan array Carpet [5] at 10 TeV (the results of analysis of small-size EAS). Thus, the energy dependence of the sidereal diurnal wave is measured at one and the same place at three different energies. This energy dependence obtained at Baksan is in agreement with the general tendency of world data: One should also note that the sidereal waves measured by Andyrchi (Fig. 1) and BUST (Fig. 2) are in a good agreement with each other and have sinusoidal form.

5. Acknowledgements

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