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Analysis of Cosmic Ray Anisotropy at Energy 10^{17} eV in Sidereal Time

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Abstract

The harmonic analysis of a distribution of shower arrival directions registered at the Yakutsk array of EAS with the energy of 10^{17} eV in sidereal time and in right ascension taking into account the summary non-uniform exposure of sky in time of the day for the sampling of 1982-1995 has been carried out. The significant anisotropy in solar time and the significant contribution of seasonal variations to obtained data for sidereal variables has been observed. This component for the sidereal vector can be taken into account from data obtained in antisidereal time. The analogous methods is also suggested for the right ascension, in which the distribution of analyzed events in zenith angle is used. When these factors have been taken into account, the statistically significant anisotropy of primary cosmic rays at 10^{17} eV is not observed: the first harmonics amplitude in right ascension less than 1.1% with the probability of 0.9. The analogous result is found from the preliminary analysis in sidereal time of all showers for 1995-1998.

1 Introduction:

The definition of the anisotropy degree of primary radiation and its dependence on the energy E_O is of great importance to solve a problem of the cosmic ray origin. At shower arrays one of basic methods to estimate the anisotropy is the harmonic analysis of shower distribution in right ascension (Linsley, 1975). At $E_O \approx 10^{17}$ eV the significant amplitude is not found (Clay et al., 1997) and to isolate a signal the great number of events is required. For the Yakutsk EAS array and analogous ones this energy is threshold energy and atmospheric conditions having daily and seasonal cycles influence on the counting rate. As at different time of the day the direction view conditions for different values of right ascension do not coincide (if an array is not located at the pole) that atmospheric variations can give the essential contribution which distorts the true anisotropy of the primary radiation. The influence of seasonal variations on analysis results in different experiments can be differed and determined by many factors: climatic conditions, itself trigger system of the array, the effective area of which depends on the temperature and pressure, selection criteria of events, possible systematic errors in the definition of parameters and energy of a shower at different atmospheric conditions and also the apparatus switching off for a time.

To investigate cosmic ray anisotropy by using data of arrays at which the arrival direction in individual events ($E_O < 10^{14}$ eV) is not measured, the analysis of distributions in sidereal time is carried out. In order to take into account the contribution of variations associated with daily and seasonal cycles, the distribution of these events in antisidereal time by the methods introduced by Farley and Storey (1954) has been used. This methods is appropriate also to analyze showers in which the direction either is determined with poor accuracy or is always not determined because of arrival time fluctuations of individual particles of a shower that occur near the detection threshold. At the same time data about a contribution of seasonal variations found in antisidereal time can be used to estimate a distortion degree of the anisotropy vector in right ascension. In present paper we used the analysis methods in sidereal time for Yakutsk array data at $E_O \approx 10^{17}$ eV and compared with a result obtained in right ascension for same sampling. Thereby the distribution of periods of the turned on array in time of the day and its influence on analysis results has been studied. The possible accounting method of seasonal variation contribution to the anisotropy vector in right ascension by using results in antisidereal time is suggested.

2 Selection of Events:

At the Yakutsk array the events are selected when signals from three neighbouring stations forming a triangle coincide. In the selection scheme two type of combinations have been given. In one there are the stations forming a grid from triangles of the 500 m side (Trigger-500), in the other - with the 1000 m side (Trigger-1000). A selection threshold is $<10^{17}$ eV for first type and $\sim 10^{18}$ eV for the second type. For all events data were recorded at the primary data medium the type of which varies with time. Prior to the summer of 1995 at the initial treatment the work database was formed in which showers according to specific criteria were selected. As the criterion the requirement was used, so at three stations the registered density is in excess of the definite threshold meaning. Since the autumn of 1982 the threshold density was 0.8 m^{-2} (>3 particles on all area of counters at the station). As the exception the some night periods were when the Cerenkov EAS radiation was registered. For such periods the criterion in density is not applied, and all showers are rewritten to the work database. Since the autumn of 1995 the treatment and accumulation were organized such that for the analysis all registered events can be used.

In this paper as before (Mikhailov and Pravdin, 1997) the events for 1982-1995 in the energy region of $3 \cdot 10^{16}$ - $3 \cdot 10^{17}$ eV with the zenith angle $\theta < 60°$ were selected in which there were 3 stations with the density more than 0.8 m^{-2}. For each year data for November to May were used. For this sampling (SAMPLING-1) the harmonic analysis of the event distribution both in solar, sidereal, antisidereal time and in right ascension (RA) has been carried out. Besides, separately for the period from December 1995 to May 1998 the analysis in sidereal time for all registered events (SAMPLING-2) has also been carried out.

3 Distribution of Array Exposure in Time of the Day:

The apparatus switching off by technical and technological reasons occur rather by day and therefore the inhomogeneous distribution of such periods in time of the day is possible. At the Yakutsk array a list of subsequent periods are constituted in which turn on and off moments are marked. To determine the relative exposure distribution in time of the day for total period of the sampling, the day was divided into minute intervals and the number of days when the array operated in each interval was summarized. Obtained values were normalized to the average. From these time periods analogous distributions by minutes of sidereal and antisidereal time can easy be found.

The nonuniform distribution in sidereal time leads to the different conditions of observations for RA and a degree of influence is defined by the zenith angle θ at which events are arrival. The greater θ the larger sky region is seen for the given sidereal time, and the irregularity would be smoothed. Therefore the correction for RA depends on the distribution in zenith angle of analyzed events and latitude of the array. To determine the exposure distribution for different values of the right ascension we at first found the zenith-angular distribution of showers. At the fixed θ and the fixed moment of sidereal time t we determined the contribution proportional to the exposure for a moment t and to the number of showers with the given θ for all possible values of RA when the azimuth uniformly changed from 0 to 2π. To find distributions we summarized such a contribution over θ and t for each interval by RA.

In Table 1 parameters of the first harmonic vectors are presented which characterize the relative exposure distributions for different variables obtained from the array operation periods for all time for the SAMPLING-1. It is seen that the irregularity is significant and the amplitude is 1.5% even for the right ascension. When these distributions are separately considered in years, then variations both in amplitude and in phase are observed. At different years the number of trigger triangles varied, therefore we in further analysis used individual corrections for each year. To take into account the nonuniform distribution arising due to the apparatus switching off the number of events in each interval is normalized to the appropriate value in the relative exposure distribution.

4 Analysis Results:

In the SAMPLING-1 150560 events have been chosen the average energy of which equals $1.6{\cdot}10^{17}$ eV and the zenith angle is 24.2°. Obtained amplitudes (r) in percent and phases (φ) in hours for the first harmonics vectors in solar, sidereal, antisidereal time and in right ascension are listed in Table 1 with the accounting and without of the exposure distribution of the array. From these results it is seen that 1) the observation irregularity for different time of the day for considered operation period of the Yakutsk array was significant (>3%) and its accounting essentially decreases the amplitude for all variables; 2) Even taking into account such nonuniform distribution for the SAMPLING-1 the significant anisotropy with the amplitude 2.76±0.37% in solar time and the essential influence of seasonal variations remains that is seen by the antisidereal vector amplitude (1.78±0.37). Let us denote by VAR the vector occurring due to seasonal variations and giving the contribution to the observed result in sidereal time. By a module it equals to the antisidereal vector and it is of the phase $\varphi_{sol}-\phi$, where φ_{sol} is a phase of the solar vector, $\phi=\varphi_{anti}-\varphi_{sol}$ (φ_{anti} is a phase of the antisidereal vector). In the last but one row of Table 1 the estimation of the primary radiation anisotropy in sidereal time after the subtraction of VAR without and with consideration for the exposure distribution is given. The amplitudes are less than one standard deviation (σ) which equals 0.52%.

Table 1. Parameters of the first harmonics for the SAMPLING-1 (150560 events)

	Distribution of the exposure		Distribution of events **without** the accounting of the exposure		Distribution of events **with** the accounting of the exposure	
	r, %	φ, h	r, %	φ, h	r, %	φ, h
Solar time	3.16	23.27	6.40 ± 0.37	22.52 ± 0.22	2.76 ± 0.37	21.56 ± 0.51
Sidereal time	1.85	8.48	3.76 ± 0.37	8.84 ± 0.38	1.65 ± 0.37	9.71 ± 0.86
Antisidereal time	1.66	14.31	3.36 ± 0.37	12.24 ± 0.42	1.78 ± 0.37	10.30 ± 0.80
RA	1.52	8.20	2.58 ± 0.37	9.11 ± 0.55	1.15 ± 0.37	10.35 ± 1.23
Sidereal-VAR			0.41 ± 0.52	9.27 ± 4.85	0.42 ± 0.52	16.47 ± 4.73
RA – VAR					0.47 ± 0.52	16.37 ± 4.23

The contribution of seasonal variations to the summary vector in right ascension can be estimated in such a way as the relative exposure by RA related to the switching-off of the array has been calculated. In this calculation the distribution in sidereal time has been given on basis of parameters obtained for the vector VAR. In the last row of Table 1 the result for right ascension is presented which is found after the subtraction of the atmospheric component calculated using the zenith distribution of showers. It coincides well with analysis results in sidereal time. In addition, for this sampling we carried out the analogous analysis for different months of the year. These results are listed in Table 2 where for the sidereal time and RA observed parameters taking into account the exposure are presented. From Table 2 it is seen that the phase both of the sidereal vector and the vector in right ascension for different seasons is varied according to the change of the solar vector direction in sidereal coordinates. This confirms that the basic contribution into the observed amplitude is caused by seasonal variations of atmospheric origin.

Once all factors for the SAMPLING-1 have been taken into account, the statistically significant anisotropy of the primary radiation at $E_O \approx 10^{17}$ eV is not observed.

At present the periods of operating array times for 1995-1999 are revised and data of all events prior to 1995 which are outside the database because of selection criteria are re-established for the purpose the analysis in detail by the total sampling. We expect more than 10^6 events the distribution of which in sidereal time can be used to estimate the anisotropy near 10^{17} eV.

Table 2. Change of the first harmonic parameters for the SAMPLING-1 for different year seasons

Months	Events	Solar time		Sidereal time		Right ascension	
		r, %	φ, h	r, %	φ, h	r, %	φ, h
11-11	16449	5.20	21.08	4.76	0.92	2.53	0.58
12-01	40526	1.26	23.51	1.34	6.73	0.96	2.73
02-03	43803	3.60	21.72	3.21	8.78	2.36	9.27
04-05	49782	2.74	21.67	2.83	11.82	2.52	11.87

From Table 1 for distributions without considering the exposure it is seen that this factor acts as atmospheric variations and their total contribution can be taken into account in the first approximation by antisidereal vector data. We carried out such a preliminary analysis for all events by data in late 1995 to 1998. 23954 showers have been analyzed in the SAMPLING-2 and results are listed in Table 3. As is seen the significant anisotropy for the sidereal time vector is not found taking into account the correction in antisidereal time as well as without it. The probability that the amplitude of the first harmonics in sidereal time more than 1% is 0.05.

Table 3 Parameters of first harmonics for the SAMPLING-2 (239554 events)

Solar time		Sidereal time		Antisidereal time		Sidereal – VAR	
r, %	φ, h	r, %	φ, h	r, %	φ, h	r, %	φ, h
0.97±0.3	21.57	0.44±0.3	9.96	0.83±0.3	10.97	0.48±0.4	18.51

5 Conclusion:

Results found in this paper show that to investigate an anisotropy it is necessary to take into account the exposure distribution in time of the day which can arise because of apparatus switching off for a time. For threshold showers there is the contribution to the observed vector in right ascension because of seasonal variations. It can be taken into account by data for the vector in antisidereal time and the zenith-angular distribution of showers. By data of the SAMPLING-1 the amplitude of the first harmonics for RA taking into account the distorting factors is 0.47±0.52%. Therefore the true anisotropy of the primary radiation in the energy region of 10^{17} eV less than 1.1% with the probability 0.9.

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