SEASON BEHAVIOUR OF THE DIURNAL INTENSITY OF MUONS WITH $E_\mu \geq 220$ GeV*

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Abstract

Baksan underground data in the five-year period of observation (1983-1987) have been analysed to study season behaviour of the amplitude of diurnal wave of cosmic ray muon intensity with $E_\mu \geq 220\ GeV$. At first step of analysis, diurnal wave of intensity was corrected for Compton-Getting effect due to orbital motion of the Earth. Analysis showed that the diurnal wave of intensity in solar time has an amplitude, changing periodically during a year, from $\sim 2 \cdot 10^{-4}$ in winter to $\sim 8 \cdot 10^{-4}$ in summer. It is important, that the phase of this wave is constant and equal to $18.5 \pm 1.5\ h$. That kind of season behaviour of diurnal wave explains the antisidereal wave (1-st harmonic: $A = (1.5 \pm 0.5) \cdot 10^{-4}$ and $F = (1.2 \pm 1.3)\ h$), and the validity of correction of the results in sidereal time by Farley - Storey method.

Introduction

Data of the Baksan underground scintillation telescope at a depth 850 hg/cm^2 (Alexeev E. N. et al., 1979) have been used to investigate sidereal anisotropy of cosmic rays (Andreyev Yu. M. et al., 1987). The median energy of primary cosmic rays is estimated as $E \approx 2.5\ 10^{12}\ eV/nucleon$. In the present paper experimental data for the period from January 1, 1983 to December 31, 1987 (for 5-year period of noniterrupted observation) have been analysed using "2 from 6 telescopes" which provides actually the omnidirectional maximal counting rate of BST namely ~ 12.2 sec^{-1} . The effective direction of this "telescope" is: declination $\delta_{eff} \sim 68°$ and right ascension $\alpha_{eff} \sim 2.8\ h$ at 0 h of local sidereal time.

For the mentioned 5-year period the first harmonic of diurnal wave were obtained in solar, sidereal and antisidereal times:

$A_{sol} = (5.04 \pm 0.36) \cdot 10^{-4}$ $F_{sol} = 18.5 \pm 0.3\ h$
$A_{sid} = (4.4 \pm 0.60) \cdot 10^{-4}$ $F_{sid} = 4.5 \pm 0.5\ h$
$A_{asid} = (1.51 \pm 0.50) \cdot 10^{-4}$ $F_{asid} = 1.2 \pm 1.3\ h$

Note, that in these data:

1. A_{sol} was corrected for Compton-Getting effect due to orbital motion of the Earth.
2. A_{sid} was corrected for A_{asid} by Farley-Storey method.
3. A_{sid} was not corrected for the effective direction of the telescope δ_{eff} and α_{eff}.

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Taking into account the last note one can observe that there is no principal change when compared with the earlier publication (Andreyev et al., 1987).

The subject of this paper is to discuss if A_{sol} and A_{asid} can be explained by the diurnal temperature wave in the stratosphere. The problem was emphasized at Adelaide (Andreyev Yu. M. et al., 1990) and consists in the following:

Though the seasonal correlation between effective temperature in the stratosphere and muon intensity at our depth was found very good (K = 0.97 and α = (0.37 ± 0.04) %/°C while theoretical value α = 0.34) the analysis of the diurnal waves was disappointing:

1. The temperature diurnal wave, as measured by balloon borne instrumentation, occurred to have 2-3 times bigger amplitude, than expected from muon wave.

2. The maximum of this temperature wave happened to be at ~ 13h of local time in disagreement with muon data and theoretical expectation, based on the temperature inertia of the stratosphere.

3. The seasonal change of the amplitude of the diurnal temperature wave happened to be too small to attribute it to the antisidereal harmonic A_{asid} , also having a wrong phase.

It is very unlikely that this discrepancy is arising due to the distance between the balloon launching place and our detector (150 km). Being quite sure, that the temperature in the stratosphere should be the main factor providing the diurnal variation of muons at our depth, we have to assume, that the balloon borne measurements give basically wrong results when dealing with so small effect (the average diurnal amplitude ~ 0.15°C). One can suppose that the heating of the instrument by the Sun also can produce a trouble.

In this paper we suggest to reverse the problem and try to find the characteristics of the diurnal temperature wave in the stratosphere using exclusively the muon intensity obtained in our experiment.

The analysis of the data and discussion

In Fig. 1 we present the monthly vectors of the first diurnal harmonic in solar time on the solar clock dial. These data are averaged over the period of 5 years and corrected for Compton-Getting effect, which means that theoretically expected Compton-Getting vector is subtracted from all diurnal vectors. To simplify the analysis all monthly intervals have been shifted by 7 days so, that the middle of all the intervals coincide with the 22-nd day of corresponding month.

In Fig. 1 small circles correspond to the experimental data, big circles indicating the error of a given monthly vector. These errors are obtained from the observed scattering of experimental hourly points. In most cases the observed errors are near to pure Poissonian ones. The numbers near the circles identify the month. One can see from the Fig. 1 that the experimental data (small circles) form a quasi elliptical contour

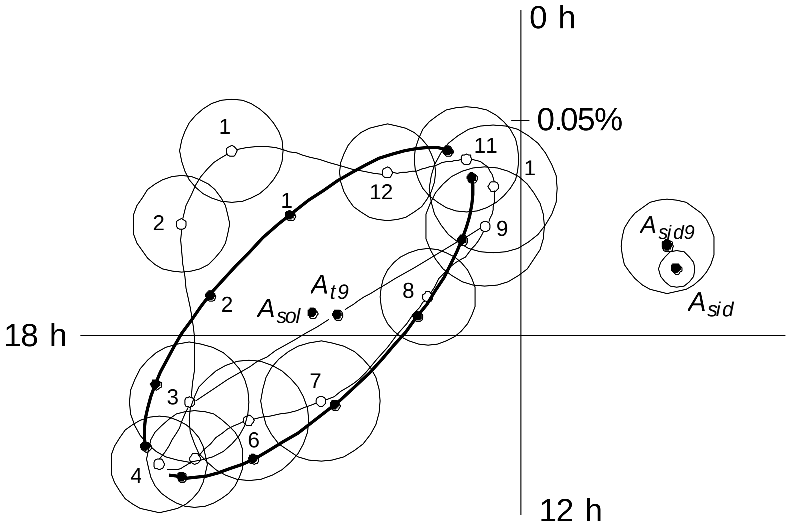

Fig. 1. Solar time dial. Small circles indicate the positions of monthly vectors of diurnal variation of muon intensity. Big circles show the statistical errors. A_{sol} - mean vector due to temperature effect. A_{sid} - corrected sidereal vector at Sep. 22. A_{t9} and A_{sid9} - obtained from only March and September data.

showing the anticlockwise rotation. A real ellipse fitting the experimental data is shown by the solid line. It shows quite a good fit except two points, January and February. At the moment we shall not discuss much the nature of this January-February anomaly. This could be purely statistical fluctuation, the probability of about several per cent. But one cannot exclude also some meteorological anomaly in the mountain area in January-February.

Obviously, each diurnal monthly vector A_m, plotted in Fig. 1 can be regarded as a sum of two vectors:

$$A_m = A_{sid.m} + A_{t.m}\,, \qquad m = 1, \ldots 12 \qquad (1),$$

where m is the number of month, $A_{sid.m}$ and $A_{t.m}$ correspondingly the real sidereal and "temperature" vectors at a given month. By the "temperature" vector $A_{t.m}$ we mean the diurnal harmonic in muon intensity caused by the diurnal wave of the temperature in stratosphere. A_{sid} in our diagram should have a constant amplitude and rotate anticlockwise making a complete turn in 1 year. The "temperature" vector A_t can have a complicated structure but as a first approximation it is reasonable to suggest a constant phase and a sinusoidally modulated amplitude with the period of 1 year. In such a case the superposition of both vectors will produce in a solar dial a contour in a shape of an ellipse. For testing this simple model let us determine A_{sid}. This can be made in two ways: 1) Take A_{sid} from table l, which is based on Fourier analysis and Farley-Storey correction and gives, in our opinion the most precise result. 2) Take the difference (A_9 - A_3) as 2 A_{sid} using the fact that $A_{sid.m}$ in September and March have the opposite phases and a likely suggestion is that $A_{t9} = A_{t3}$. Both results are shown in the right side of the Fig. 1. This right side should be better regarded not as a solar time dial, but a sidereal time dial (or solar dial at September 22). Fig. 1 shows quite a good agreement of these two approaches to obtain A_{sid} and also to obtain the mean value of A_{sol} . Fig. 2

shows the result of subtractlon $A_{t.m} = A_m - A_{sid.m}$ (here $A_{sid.m}$ was calculated on the basis of A_{sid9}). Except A_{t1} and A_{t2} there is a good agreement with the suggestion of a constant phase of the "temperature" vector. A very big modulation of the amplitude of $A_{t.m}$ with maximum in summer solstice and minimum in winter solstice is demonstrated. The following approximation has been chosen to describe the "temperature" variations of the muon intensity in our case:

$$I(T)/I_0 = 10^{-4} \cdot (5 - 3Cos(2\pi(T+9)/365)) \cdot Cos(2\pi(T-18.5/24)) \qquad (2),$$

where T is the number of day in local solar time.

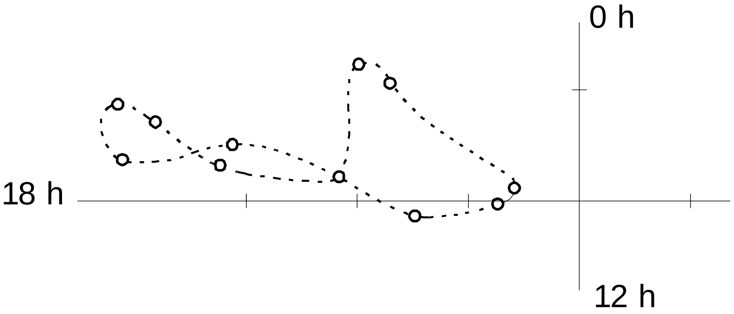

Fig.2. Season behaviour of monthly vectors variation due to the temperature of stratosphere.

Using this approximation for the "temperature" effect and A_{sid} from the table the predicted behaviour of monthly vector A_m have been calculated and the result is shown in the Fig. 1 by the solid line. We believe that the given interpretation of the solar diurnal variation of muon intensity in our experiment is basically correct. It explains also the antisidereal wave of muon intensity. If this interpretation is really correct it demonstrates probably for the first time that you can obtain more precise results in investigating the geophysical phenomenon using cosmic rays, than using modern direct methods. The most striking in the suggested (obtained ?) diurnal temperature wave in stratosphere is its deep seasonal modulation. This certainly should strongly depend on the latitude (43° N at Baksan). The mechanism of this modulation in our opinion should mostly depend not on duration of the sunshine, but on the change of the zenith angle of the Sun.

Conclusions

1. Temperature vector of the intensity has the average value

$$A = (5.04 \pm 0.36) \times 10^{-4}, \qquad F = (18.5 \pm 0.3)\ h.$$

The phase of the temperature vector is constant during a year, however, its amplitude changes from ~ $2 \cdot 10^{-4}$ in winter solstice to ~ $8 \cdot 10^{-4}$ in summer solstice.

2. The seasonal change of temperature vector explains the antisidereal wave and proves the validity of correction of the results in sidereal time by Farley-Storey method.

References

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