DETERMINATION OF THE TRANSMISSION OF THE LOWER LAYERS OF THE ATMOSPHERE USING THE ATTENUATION OF THE CHERENKOV RADIATION OF EXTENDED ATMOSPHERIC SHOWERS

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Received February 25, 1991

The method for determining the transmission of the lower layer of the atmosphere (6–7 km thick) is described, in which a light source with the spectrum $\frac{d^2W}{dld\lambda} \sim \frac{1}{\lambda^3}$ *is formed by the Vavilov–Cherenkov radiation of charged particles of the extended atmospheric showers (EAS), in the process of the interaction between the cosmic rays and air atoms.*

Average transmittance of this layer in the wavelength range $\lambda_1 - \lambda_2 = 300$*–800 nm obtained under favorable optical conditions of observation with the help of a Yakut integrated setup used for observing the extended atmospheric showers, are presented.*

INTRODUCTION

The central Yakut region has clearly continental climate, for which the winter–summer temperature gradient may be as large as ~ 100°C. In summer the temperature often exceeds 30 – 35°C, while winter is characterized by continuously low temperatures, varying usually from 35 to 50°C, and by negligible snow precipitations. Because of long–time low temperatures (winter lasts for 5–6 months) the atmosphere in the central Yakut region becomes virtually frozen out in winter, i.e., free of water vapor. This fact as well as the absence of any powerful industrial sources of pollution of the environment in this region favors optical measurements.

Since the 70's the Cherenkov radiation of the atmosphere emitted by a cascade of charged relativistic particles produced in the process of interaction between cosmic rays and air atom nuclei has been recorded in the optical range using a Yakut integrated setup used for observing the extended atmospheric showers (EAS).[1]

In order to correctly change over from the parameters of the atmospheric Cherenkov light of the EAS, measured by the setup, to the characteristics of the primordial cosmic radiation, we must estimate the total losses of light over the entire propagation path. Such an estimate has been obtained with the help of a method, which employs the Cherenkov radiation, attenuated in the atmosphere on its way to a photodetector, as a light source.

EXPERIMENTAL SETUP

The Yakut setup simultaneously records the electron and muon components of radiation as well as the Cherenkov light of the showers. Figure 1 shows a layout of the setup, which incorporates 59 observation stations. The baseline between these stations is 0.5 and 1 km. The Cherenkov light is recorded in the case in which two signals of the adjacent scintillation counters coincide with the Cherenkov pulse. This coincidence confirms that the given optical signal belongs to a shower and reduces the probability of an erroneous triggering in the case of an increase in the background radiation of the night sky. All information about the shower is accumulated in autonomous memory of each station and by a special instruction is sent to the setup center (a CAMAC system + an SM–3 computer), where it is processed and stored on magnetic carriers.

Photomultiplier tubes of the FEU–49B and HR–2041 types served as detectors of the Cherenkov radiation. Their sensitivity and spectral characteristics corresponded to the requirements for measurements of the Cherenkov light.

The Cherenkov detector was made in the form of a metallic tank, in which a PMT are mounted in such a way that the photocathode was oriented upward. The detector cover was automatically opened and closed by an instruction from the setup center, thereby ensuring a light screening during a day. In winter in order to protect the photocathode from dust and snow and from frosting, it was blown out by a warm air. The detector operated without additional optics and the year round.

The voltage divider and the operational regime of the PMT were chosen so as to account for an operation with an increased current (the basic resistance of the divider R = 40–100 kΩ), associated with the time variations of the background radiation of the night sky. The adjustable background loading did not exceed 1000 Hz and was continuously digitized and recorded on a paper with the help of a high–speed automatic plotter. The amplitude of the Cherenkov pulse was recorded by a 8 bit analog–to–digital converter, which operated in the impulsing circuit with a frequency of 500 kHz (Ref. 4). In order to avoid a superposition of noise, caused by the fluctuations of the radiation of night sky and by the intrinsic noise of the PMT, on the valid signal, a pulse blocking of the PMT was employed. Its performance was described in Ref. 5.

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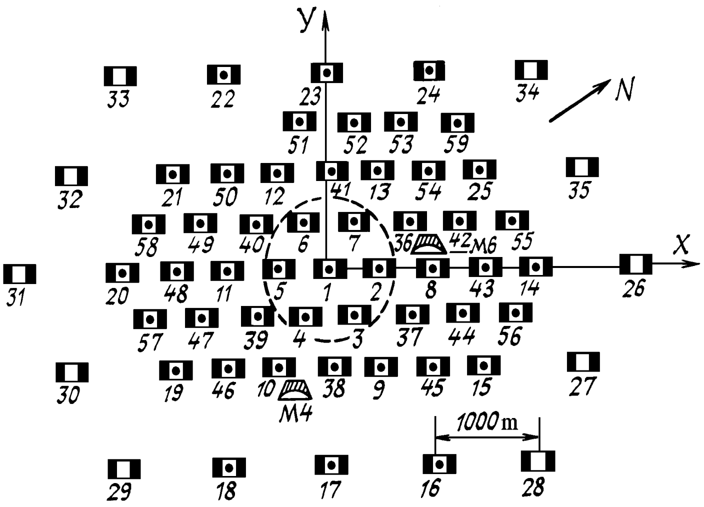

FIG. 1. Layout of the stations of the Yakut integrated setup used for observing the EAS. The stations 1–25 have two scintillation counters with the 2 m^2 *receiving apertures and the detector of the Cherenkov light with the single PMT. The stations 26–35 are without the Cherenkov light detector and the stations 36–54 have the detector of the Cherenkov light with the three PMT's.*

The online control of the electronics in the Cherenkov channel was performed continuously using the background radiation of the night sky and periodically with the help of a test signal transmitted from the setup center to check in general the state of each channel. The Cherenkov channel was calibrated using a reference plastic scintillator (calibrated in the number of photons per square meter) prior to the beginning and after the termination of the observation period.[6]

The general control of the setup performance as well as acquisition, storage, and processing the entire body of information were performed in the setup center by means of a system based on the CAMAC modulus coupled with the Elektronika–60, SM-3, and SM–4 computers operating in a continuous regime.[7]

METHOD OF MONITORING THE ATMOSPHERIC TRANSMISSION

A flux of relativistic electrons of the EAS gives rise to a flash of the Cherenkov light of duration 10^{-7} sec.[8] Such a pulse of light can be recorded against the background of the radiation of the night sky with the help of the PMT's.

Figure 2 shows an integrated amplitude spectrum of light pulses comprising an amplitude spectrum of fluctuations of the background radiation of the night sky (dashed line) and an amplitude spectrum of the Cherenkov light of the EAS (solid line).

In order to quantitatively describe the shape of the integrated spectrum, the power approximation $F(> Q_{\text{th}}) \sim Q^{-n}$ was used, where $F(> Q_{\text{th}})$ is the integrated repetition rate of the pulses, whose amplitudes are larger than the threshold amplitude and n is the power characterizing the spectrum slope. In this case the background radiation spectrum of the night sky may be described by $n = 5$–10.

In accordance with Ref. 9, the integrated spectrum for the amplitude $Q_0 \le 100$ photons$\cdot$ cm$^{-2}\cdot$ eV^{-1} experiences a break.

This break is characterized by the following values of the spectrum index:

$n_1 = 1.50 \pm 0.03$ for $Q < Q_0,$
$n_2 = 2.12 \pm 0.04$ for $Q > Q_0$

and is explained by the nature of the primordial cosmic radiation.

Employing a high–speed technology we can separate out the section of the integrated spectrum of the Cherenkov light amplitudes with sufficiently high confidence and then to make use of it in order to monitor the state of the atmosphere in its lower part, starting from an altitude of 6–7 km above the ground.

In the proposed method the mass of the atmospheric column of the effective light generation x_m was assumed to be well known. Measuring the integrated light pulse repetition rate during the given time period and comparing it with the maximum possible rate, which was realized under conditions of the best atmospheric transmission, one can find the relative atmospheric transmission based on the following formula:

$$T_m = \left[\frac{F_{\text{i}}(> Q_{\text{th}})}{F_{\text{c}}(> Q_{\text{th}})}\right]^{1/n} . \qquad (1)$$

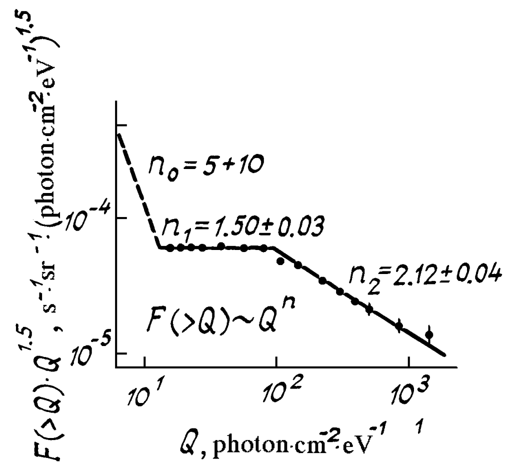

FIG. 2. Integrated amplitude spectrum of the light pulses. Points denote the experimental data according to Ref. 9. $F(>Q) \cdot Q^{1.5}$ photons$\cdot$ cm$^{-2}\cdot$ eV^{-1}

Here, $F_i(> Q_{th})$ and $F_c(> Q_{th})$ are the integrated repetition rates of the pulses of the Cherenkov light of the EAS when they exceed the given recording threshold, during the given observation period and during the best, with respect to the transmission, calibration period and n is the power of the pulse spectrum of the Cherenkov light of the EAS (see Fig. 2).

In order to determine the absolute transmission of the atmosphere, we must know the actual losses of light at the calibration night. We assumed that, at such a night, the light losses due to aerosols are minimal and constitute half the losses due to Rayleigh scattering of light. The coefficient of Rayleigh light scattering, averaged over the wavelength λ, is found from the formula[10]

$$\overline{K_R(x)} = \frac{\int_{\lambda_1}^{\lambda_2} K_R(x, \lambda) W(\lambda)\, s(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} W(\lambda)\, s(\lambda)\, d\lambda}, \qquad (2)$$

where x is the mass of the atmospheric column of unit cross section, in g·cm^{-2}, from which the light comes, $W(\lambda)$ is the Cherenkov radiation spectrum, and $s(\lambda)$ is the spectral characteristic of the PMT.

In this method, it is more convenient to represent the transmission $\overline{T_R(x_m)}$ as a function of the mass of the atmospheric column of effective generation of the Cherenkov light x_m in g · cm^{-2} (Ref. 2). The atmospheric transmission of the Cherenkov light then with an account of Rayleigh scattering[6] is written in the form

$$\overline{T_R(x_m)} = (1 - \overline{K_R(x_m)}) = 0.90 + 0.025\left(\frac{x_m - 700}{100}\right), \qquad (3)$$

and the function of light transmission at the calibration night, in accordance with our assumption, has a form

$$\overline{T_c(x_m)} = (0.85 \pm 0.05) + 0.04\left(\frac{x_m - 700}{100}\right). \qquad (4)$$

Finally, the absolute atmospheric transmission as functions of x_m and zenith angle of arrival of light θ can be represented in the form

$$\langle T(x_m,\theta)\rangle = \langle T_m(x_m,\theta)\rangle\ ,\ \overline{T_c(x_m,\theta)}\ , \qquad (5)$$

where $\langle T_m(x_m, \theta)\rangle$ is determined from the resulting patrol measurements of the integrated repetition rate of the Cherenkov pulse averaged over 15 min observation intervals.

RESULTS OF OBSERVATIONS

We have measured T_m with our Yakut setup since 1974. In the first measurements from 5 to 13 observation stations were involved, lately 14 new detectors of the Cherenkov light were added to the setup. In all cases the time period needed to acquire the integrated amplitude spectrum equaled 15 min for each observation station.

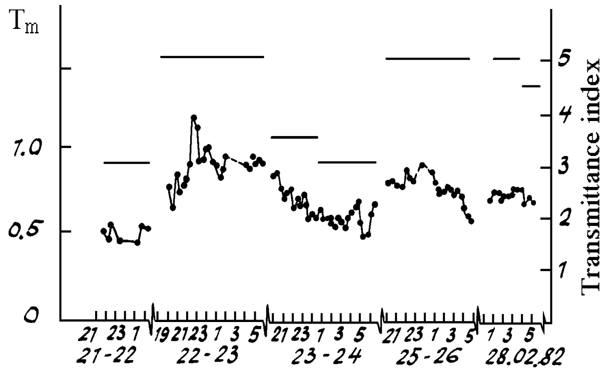

FIG. 3. Relative transmission of the atmosphere over the Yakut setup. The lines indicate the visual estimate and the points stand for the method of Ref. 3.

Figure 3 shows the 15 min measurements of the relative atmospheric transmission averaged over one hour as a function of the local time. Small–scaled variations of T_m during the night and, as a whole, a correlation with visual estimates of the atmospheric transmission (solid lines) can be seen. As one can see from Fig. 3, the atmospheric transmission may change significantly during the night and, its absolute values are even larger than 1.0, which can be explained by the occurrence of nights with the atmospheric transmission better than in the calibration night.

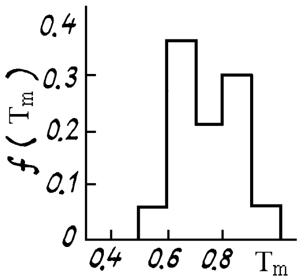

FIG. 4. Distribution function for the relative atmospheric transmission f(T) (since December 1981 to March 1982). $T_m = 0.73 \pm 0.01$.

In order to analyze the parameters of the EAS and energy spectrum of the primordial cosmic rays, one should know the atmospheric transmission averaged over the period of many years. An example of such an averaging the data obtained since December 1981 to March 1982, is shown in Fig. 4. Here the values of T_m are summed over the hour time periods under the assumption that the optical state of the atmosphere during this period does not change significantly.

These data enable us, based on the above-described technique, to determine the average transmission of the lower atmospheric layers[2]

$$\langle T(x_m,\theta)\rangle = (0.71 \pm 0.05) + 0.06\left(\frac{x_m - 700}{100}\right) - 0.58(\sec\theta - 1). \qquad (6)$$

The large number of photodetectors in the setup, which are distributed over an area of ~20 km^2, makes it possible to retrieve not only the average atmospheric transmission, but also the information about small–scaled inhomogeneities of the atmospheric optical properties over the individual observation stations.

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