PRIMARY COSMIC RAY SPECTRUM MEASURED USING CHERENKOV LIGHT REFLECTED FROM THE SNOW SURFACE

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ABSTRACT

The experimental data obtained in Tien–Shan mountains and the first methodical data obtained with balloon–borne detector are presented.

INTRODUCTION

The results of recent cosmic ray energy spectrum measurements in the energy range $10^{15}-10^{19}$ eV do not agree with each other sufficiently well. For this reason the actual problem is to carry out further experiments using various methods.

This work is based on the Prof. A.E. Chudakov's (1972) suggestion to detect the Cherenkov light reflected from the snow surface. The intensity of Cherenkov light is proportional to the energy of the primary cosmic ray particle. The wide–angle balloon–borne or airborne small detector makes it possible to have a sensitive area up to some hundred km^2. The first unaccomplished attempt of such an experiment was undertaken by C.Castagnoli, G.Navarra et al. (1981).

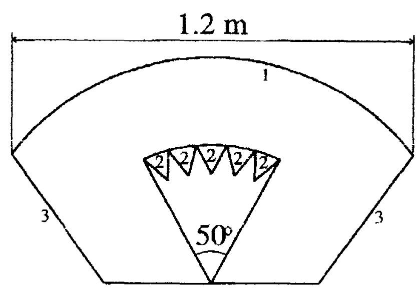

Fig. 1: SPHERA optical scheme: 1 – mirror surface, 2 – PMT, 3 – diaphragm

DETECTOR ARRAY

SPHERA detector array was elaborated for balloon–borne experiment (Antonov et al., 1975, 1986, 1995, 1997). Figure 1 shows the scheme of this array. The light spots are detected by 19 photomultipliers (FEU–110) situated on the focal surface of the spherical mirror. Dark violet filters and shifters are used with photomultipliers to decrease the influence of the starlight background. The angular aperture of detector is about $50^o \times 50^o$. Detector lifted to the altitude H make it possible to have a sensitive area $\sim H^2$.

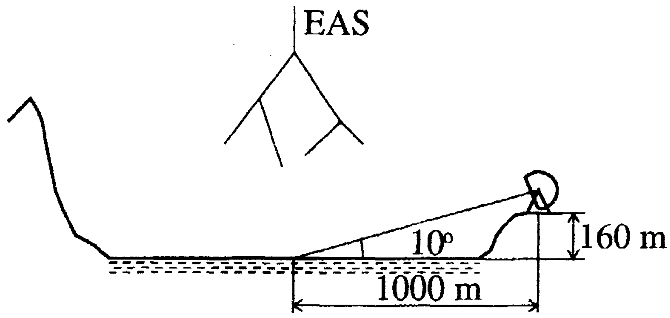

Fig. 2: Geometry of experiment on B. Alma–Ata lake.

TIEN–SHAN EXPERIMENT

The first measurements were carried out in the Thien–Shan mountains in winter 1993 (Figure 2). SPHERA detector was situated on the 160 m high mountain ledge nearby the B.Alma–Ata lake (2500 m above sea level) to detect Cherenkov light reflected from the snow surface of the lake.

The area of the lake is about 0.7 km^2.

The average inclination angle of the detector optical axis to the horizon was 10^o. Cherenkov light is reflected from the snow surface according to the Lambert reflection law: $I(\Theta) = I_0 \cdot \cos\Theta$, where $I(\Theta)$ is flux reflected at angle Θ, I_0 — normally reflected flux. So only about $\cos 80^o \sim 0.17$ of normally reflected light was detected in this experiment.

13 PMTs were used in the experiment. The trigger condition was — pulse amplitude in one of central PMTs (condition M1) or in one of central PMTs and one of neighbour PMTs (condition M2) must exceed the threshold.

Time stability of the detector and transparency of the atmosphere were monitored by the periodical PMTs current measurements and by the trigger rate of detector. Average registration rate was 2.6 min^{-1}. Measured starlight background was $I_o \simeq 10^8 ph\ sm^{-2} sr^{-1} s^{-1}$.

Two series of measurements were carried out under trigger condition M2: with covered and with open detector. In measurements with covered detector pulses were caused by Cherenkov light emission of charged particles in glass of PMT tube and light filter.

The experimental differential spectra of pulse amplitude total over the four central PMTs are shown in Figure 3. In following analysis spectrum of covered data was subtracted from that of open one.

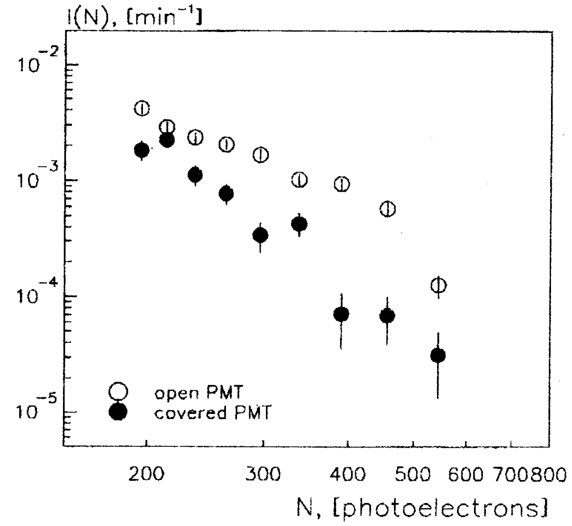

Fig. 3: Amplitude spectra of detected events: open PMT – 4871 events, exposition 1510 min; covered PMT – 1613 events, exposition 956 min.

To obtain energy spectrum it was necessary to take into account that some part of light spot falls outside the lake area. It was necessary to determine effective registration area also. For this two purposes Monte–Carlo simulation was done.

To derive the absolute primary particle fluxes it was necessary to know the effective space angle of the showers detection. The shower angular distribution was not measured in this experiment but was estimated. It was assumed that the attenuation of the inclined showers was caused only by Rayleigh scattering. The effective space angle was $\simeq 3.3$ ster (on the base of this estimation).

Primary cosmic ray flux at the energy 10^{17} eV obtained in this experiment is in agreement with other experimental data (Figure 4).

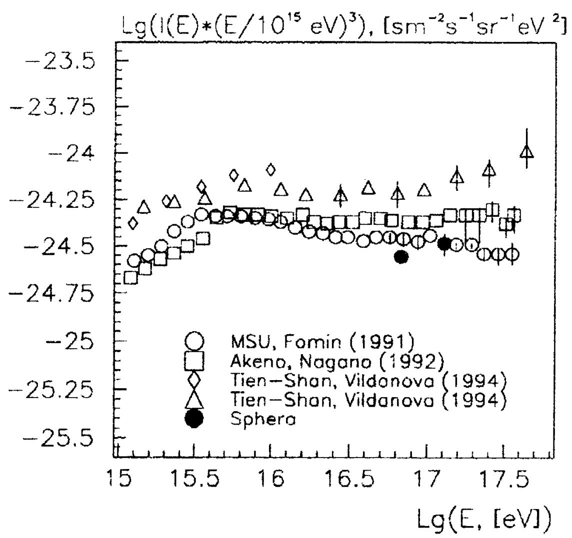

Fig. 4: The differential energy spectrum.

Energy threshold in this experiment was due to the large dead time of the device, not by starlight background.

CONTEMPORARY STATUS OF SPHERA DETECTOR

During 1994–96 the detector SPHERA was improved significantly.

The amplitude measurements are complimented by the time analysis of PMT pulses. It will allow us to analyse the detected events more completely.

The trigger rate ability is increased up to 50 Hz by using fast electronics and microcomputer. In balloon–borne experiment the reflected light intensity increases by 6 times according to the Lambert reflection law. This two reasons allow us to decrease energy threshold to $\sim 10^{15}$ eV under condition of starlight background only. The size of detector storage is sufficient to store $\simeq 3.6 \cdot 10^6$ events.

The detector electronics measures the integral of light pulse in PMT, pulse duration and intervals between pulses. The 30-ns discreteness allow to reliably reject events simulated by charged particles in the PMT tubes and filter glass. It makes possible to determine the arrival direction of EAS too.

The first lifting of SPHERA detector to 0.9 km altitude by fastened balloon was carried out in winter 1997. It was possible to perform this methodical experiment only under condition of significant light background from some kilometers far medium town. Intensity of light background I_b was found to be higher than in Tian-Shan experiment by some hundreds times ($I_b \sim$ some units $10^{10} ph\ sm^{-2} sr^{-1} s^{-1}$).

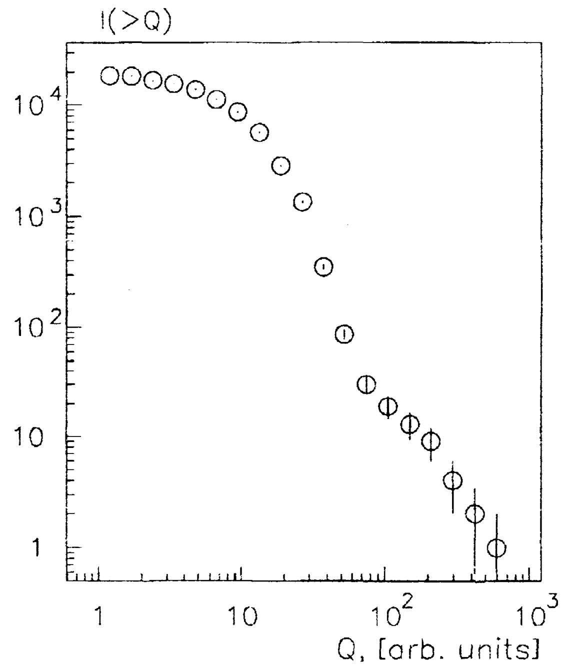

Fig. 5: Experimental pulse charge integral spectrum of trigger PMT.

19 PMTs were used in the experiment. The trigger condition was – pulse amplitude in any PMT must exceed the fixed threshold (~ 50 mV). Were detected $\sim 3 \cdot 10^5$ events during 315 min, most of them was caused by light background.

The processing of the obdated data is on the way. There are some preliminary results.

Figure 5 shows trigger PMT pulse charge integral spectrum measured during last 200 min of experiment when the light background was smaller. Figure 6 shows the control laboratory integral spectrum. The PMT was lighted by lamp in last case to imitate light background. Spectrum on Figure 5 has more flat right part but laboratory one on Figure 6 hasn't it. So it may be caused by Cherenkov light of EAS.

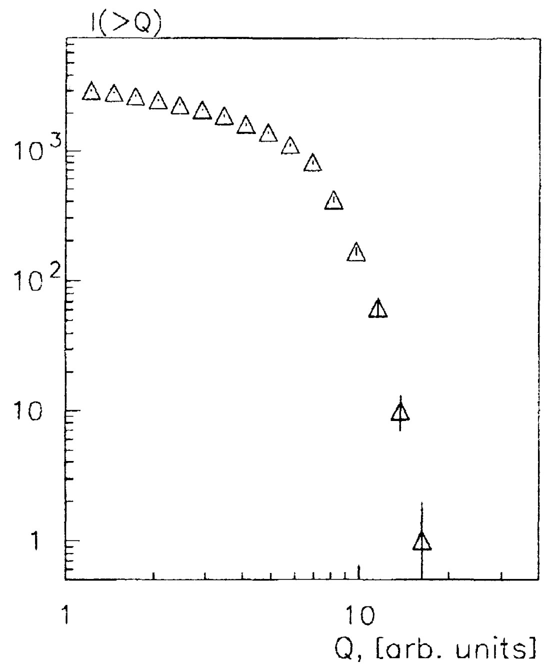

Fig. 6: Laboratory pulse charge integral spectrum. PMT was lighted by lamp.

The intensity of events in more flat right part of spectrum corresponds to the threshold energy $E_{thr} \sim$ some units 10^{16} eV. This value agrees with light background I_b ($E_{thr} \sim \sqrt{I_b}$), if we take into account the change of light reflection conditions in balloon–borne experiment vs Tien–Shan experiment.

DISCUSSION AND CONCLUSIONS

The experiment showed that the method of detection of Cherenkov light reflected from the snow surface is appropriate to the cosmic ray energy spectrum measurement. It is possible to ensure large sensitive area and to measure cosmic ray energy spectrum in wide range of energies ($10^{15} - 10^{20}$ eV) with small wide–angle balloon–borne detector. Sensitive area in such an experiment is continuous but not discrete as for large ground–based EAS arrays. It allows to detect full Cherenkov light flux even for extremely high energy EAS.

We plan to carry out measurements at altitudes 1–3 km above snow surface using the fastened balloon in winter 1997–98 under condition of small light background. In the future it is desirable to perform the large–scale measurements in the Arctic or Antarctic to detect EAS with energy up to $\sim 10^{20}$ eV. One such session will be enough to get the amount of data on EAS with $E \geq 10^{19}$ eV comparable with that of Yakutsk array. Table 1 shows the estimated event number to be detected by SPHERA detector for given flight height H and detection time t.

Table 1: Estimation of EAS with $E > E_o$ Number to be Detected by SPHERA Detector

			fastened balloon		**4 flights of balloon around the South Pole**
		H, km	1	3	40
		S, m^2	$\simeq 10^6$	$\simeq 10^7$	$\simeq 1.6 \cdot 10^9$
E_o, eV	$I(> E_o)$,	E_{thr},eV	$\simeq 10^{15}$	$\simeq 5 \cdot 10^{15}$	$\simeq 5 \cdot 10^{17}$
	$(\text{m}^2 \cdot \text{hour} \cdot \text{sr})^{-1}$	t, hour	$\simeq 100$	$\simeq 100$	$\simeq 500$ (20 days)
$1 \cdot 10^{15}$	$5 \cdot 10^{\;3}$		$1.5 \cdot 10^6$	—	—
$1 \cdot 10^{16}$	$6.5 \cdot 10^{-5}$		$2.0 \cdot 10^4$	$2.0 \cdot 10^5$	—
$1 \cdot 10^{17}$	$6.5 \cdot 10^{-7}$		$2.0 \cdot 10^2$	$2.0 \cdot 10^3$	$1.6 \cdot 10^6$
$1 \cdot 10^{18}$	$6.5 \cdot 10^{-9}$		2.0	20	$1.6 \cdot 10^4$
$1 \cdot 10^{19}$	$6.5 \cdot 10^{-11}$		—	—	$1.6 \cdot 10^2$
$3 \cdot 10^{19}$	$6.5 \cdot 10^{-12}$		—	—	16

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