First results of primary cosmic ray spectrum measurements using balloon–borne detector SPHERE

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Abstract

Results of the first winter 1998 measurements of the cosmic ray energy spectrum above 10^{16} eV with SPHERE detector are presented. Detector was lifted by fastened balloon above snow field to 1 km altitude. Cherenkov light of the air showers reflected from the snow was detected. Detector consists of the 1.2 m diameter spherical mirror and the mosaic of 19 photomultipliers.

1 Introduction

The method used in this experiment is based on the A.E. Chudakov's (1972) idea to detect the Cherenkov light of air showers reflected from the snow surface. The small wide–angle balloon–borne or airborne detector makes it possible to have a sensitive area up to some hundred km^2. The intensity of the EAS Cherenkov light is proportional to the energy of the primary cosmic ray particle so this method is the calorimetric one.

SPHERE detector array was elaborated for balloon–borne experiment (Antonov, 1975, 1986, 1997). The first measurements (Antonov, 1997) with the simple detector prototype were carried out in the Thian–Shan mountains in winter 1992–93. Detector was situated on the 160 m high mountain ledge nearby B.Alma-Ata lake and detected the Cherenkov light of the air showers reflected from the snow surface of the lake. During 1995–97 the improved balloon–borne detector was created and two methodical liftings of the detector by fastened balloon were carried out under conditions of strong light background.

The results of the first successful balloon–borne experiment with SPHERE detector carried out in winter 1998 are presented in this paper.

2 Detector setup

Figure 1 shows the scheme of SPHERE detector array. The light spots are detected by 19 photomultipliers FEU–110 located on the focal surface of the 1.2-m diameter spherical mirror. Dark violet filters and shifters were 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 ensures a sensitive area $S \sim H^2$.

The detector electronics measures the integral of light

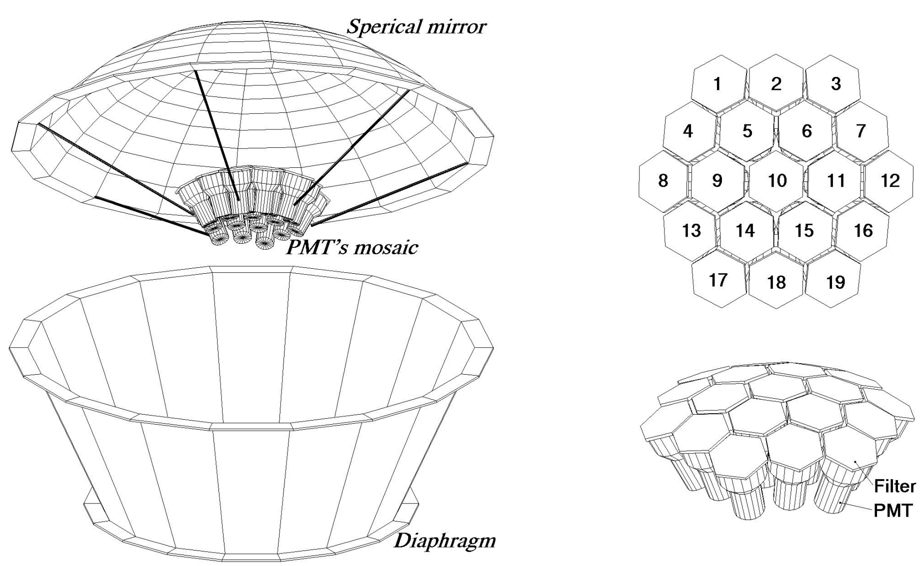

Figure 1: 3-D scheme of the optical part of the SPHERE detector.

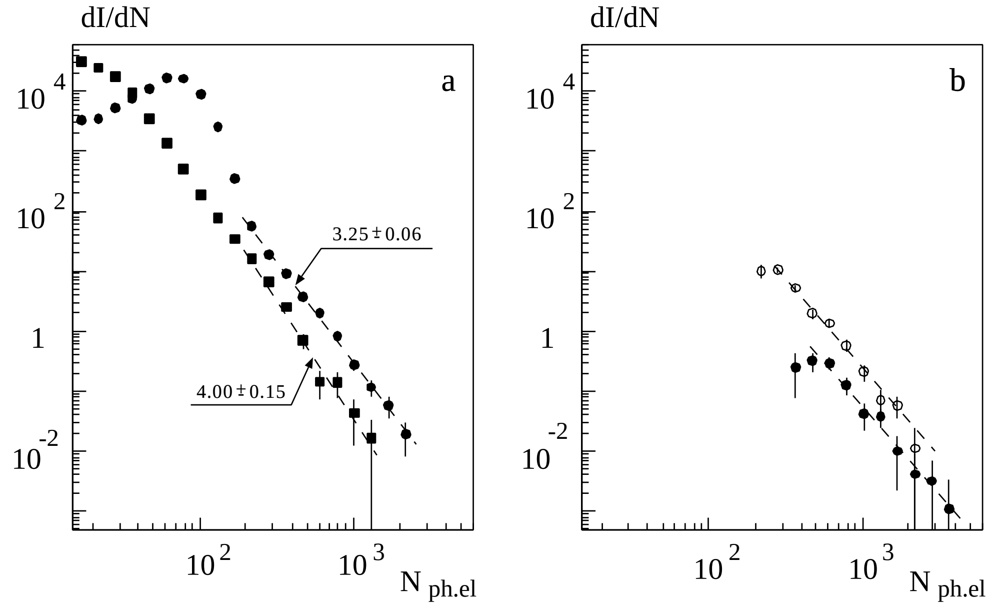

Figure 2: Distribution of detected events over sum of photoelectrons in trigger PMTs.
a, circles — balloon experiment, 345853 events, squares — laboratory, 166695 events (events are caused by Cherenkov light emitted by particles in the PM tube glass); b, difference between distributions measured in balloon experiment and in laboratory with light imitation, open circles are M1, closed circles are M2.

pulse in each PMT channel during 2.0 μs and the times of the pulse beginning and end in each trigger channel. The trigger condition is caused by the pulse magnitude exceeding the threshold level in any PMT channel (trigger M1) or in any two channels (trigger M2). Onboard computer controls the electronics and accumulates the data. The parameters of electronics, the gain and the current of photomultipliers and the temperature inside the box with electronics are controlled periodically.

3 Data analysis

Detector was elevated to 1 km altitude by fastened balloon in the experiment. Time of measurements is 469 min (157 min — under trigger condition M1, 312 min — M2).

Circles on figure 2a show the distribution of all detected in the experiment events over sum of photoelectrons in trigger PMTs (trigger condition M1). The steep part of the spectrum near the threshold level is caused by the light background (starlight and other light). Some other part of events is caused by the Cherenkov light emitted by charged particles in PM tube glass. Squares on figure 2a show the distribution of such "particle" laboratory-detected events. The slopes of these spectra are different. The distributions of events detected under trigger condition M2 are the same.

To reject events caused by the background light and charged particle events laboratory measurements with light background imitation were carried out. PMTs were lighted by lamp to provide the same PMT current as in the balloon measurements. The difference between all events distribution and this laboratory spectrum gives the detected EAS Cherenkov light events distribution (figure 2b).

To go on to the energy spectrum the Monte–Carlo simulation was done. The fact that some part of the Cherenkov light spot of air shower may fall outside the area observed by detector and the angular distribution of the primary particles were taken into account. The Yakutsk experimental data on the EAS Cherenkov light lateral distribution (Djakonov, 1993) were used. The effective registration area and space angle Ω were evaluated.

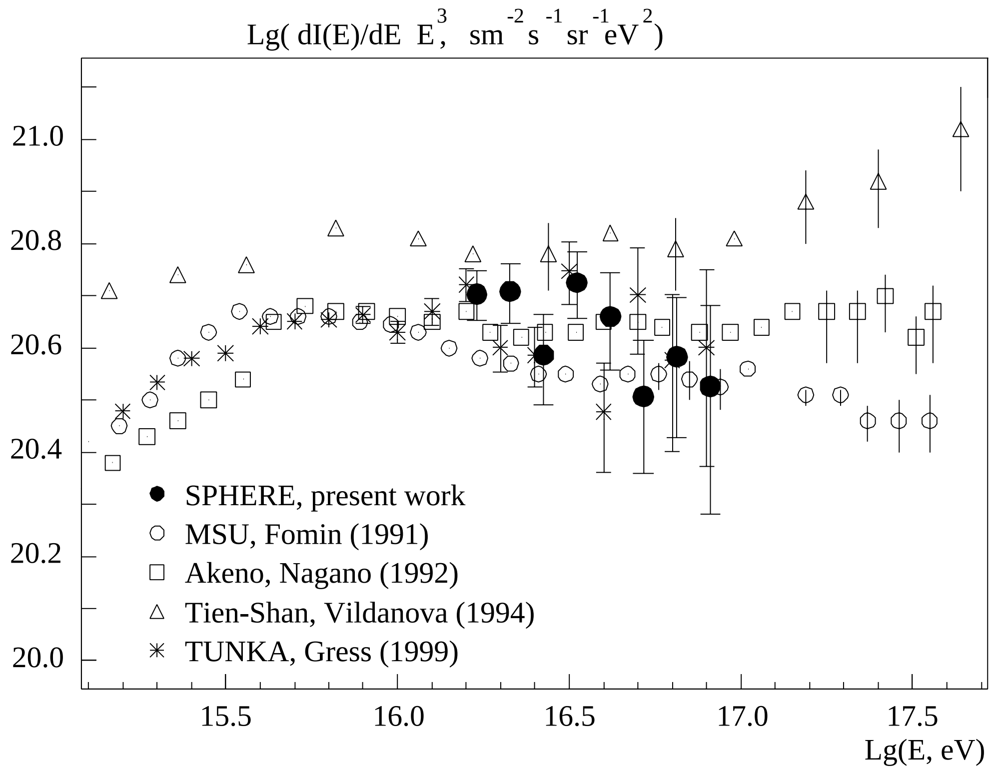

Figure 3: Differential energy spectrum

Figure 3 shows the final primary cosmic ray spectrum in the energy region $10^{16} - 10^{17}$ eV obtained in the experiment. The M1 and M2 points were normalized with each other using the integral fluxes above 30 PeV. Points on the figure 3 are the M1 and M2 averaged points. The total systematic uncertainties of the energy are 30-35%. Data obtained in the experiment are in a good agreement with results of other experiments. The experimental points may be approximated by power law with $\gamma = 3.24 \pm 0.14$.

The mean light background measured in the experiment in the region of the quantum sensitivity of PMT FEU–110 covered by the shifter ($\sim$ 260–520 nm) amounts $(5.7 \pm 1.4) \cdot 10^{12}$ photon m^{-2} s^{-1} sr^{-1}. The violet filter decreases background by a factor of 15 ± 1.

4 Conclusions

The first balloon experiment was carried out using new method. First results show the agreement with other experimental data. Now SPHERE detector is improved for more precise energy spectrum measurements: the charged particles detection will completely rejected and therefore the spectra subtraction will excluded. The reconstruction of the EAS direction and the Cherenkov light lateral distribution for the main part of detected EAS by the pulse time analysis becomes possible. Figure 4 shows the example of one EAS detected under trigger condition M2 in the balloon experiment. The numbers in each column on the figure 4 correspond to the values measured by SPHERE electronics in each PMT channel: the integral of light pulse during 2.0 μs in photoelectrons, pulse begin and end times in units of 30 ns. One column shows the data of one PMT. The column arrangement agrees with the PMTs order in the mosaic (figure 1). The encircled data correspond to the trigger PMT in event.

The main advantages of this method follows.

1. This method is the calorimetric one. It makes it possible to carry out measurements in wide energy range ($10^{15} - 10^{20}$ eV) using one balloon–borne detector at different balloon elevations. One or two longtime polar

flights of the balloon with detector allow to obtaine the same number of events with energy $10^{19} - 10^{20}$ eV as there is at all ground–based arrays now.

2. Sensitive area in such an experiment is continuous but not discrete as for large ground–based EAS arrays. The results of the measurements do not depend on the shape of Cherenkov light lateral distribution and its fluctuations. It is important especially for extremely high energy EAS ($10^{18} - 10^{20}$ eV).

3. The detector is very small and is not expensive especially in comparison with ground–based arrays.

4. SPHERE detector may serve as the base of prototype of the spacecraft–borne detector. For this purpose the increasing of pixel number (from 19 up to $\sim$ 64) in photodetector, electronics improvement and detection of each pixel pulse shape are necessary. After such an improvement the simultaneous measurements of EAS Cherenkov light flux and fluorescent track becames possible.

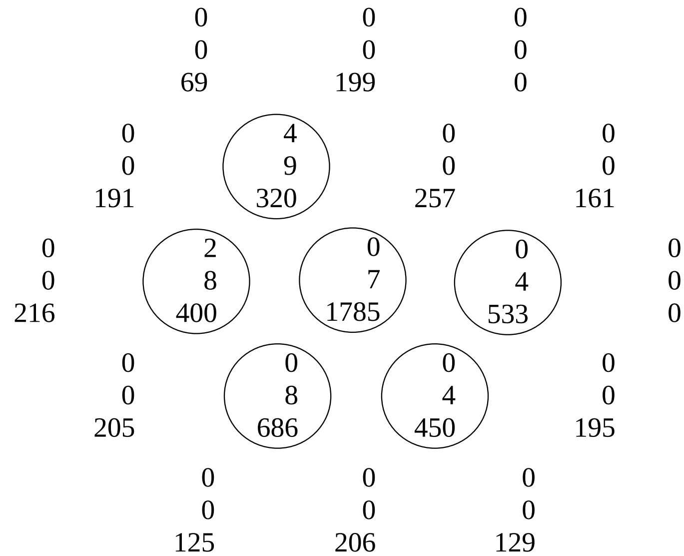

Figure 4: Example of event detected by SPHERE array

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