# Sphere Project

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Received 20 October 2002;
final version 31 December 2003

Relatively simple detector SPHERE-2 (spherical mirror $\sim 1.5m$ diameter and retina of 100 pixels) is presented for the Antarctic balloon-borne measurements of the CR spectrum. Long time winter flight make it possible to measure the spectrum above $10^{20}eV$. Comparison with satellite and ISS projects of the nearest future show that the efficiency of this detector is sufficiently high. The energy threshold is less ($\sim 10^{18}eV$). The accuracy of the energy definition is high as two methods are together - the measurement of the EAS fluorescent track in the atmosphere and the measurement of the full flux of the EAS Cherenkov light.

Preliminary results of the 2000 year measurements using more simple balloon-borne detector SPHERE-1 are presented. Detector was lifted by fastened balloon above snow field to 1km altitude. EAS Cherenkov light reflected from the snow was detected. Some indication of spectrum peculiarity near the energy 3-4$\times 10^{16}eV$ was obtained. The first attempt to estimate the Cherenkov light lateral distribution by means of this new method has been made.

*PACS*: 62.20
*Key words*: Sphere Project, balloon, cosmic ray, hi-energy particles.

## 1 Introduction

The aim of experiment SPHERE is study of primary CR energy spectrum structure and nuclear composition in the region above $10^{15}eV$. One of the most adequate calorimetric methods of the primary particle energy measurement in this energy region is the full flow of EAS Cherenkov light measurement. Experiment SPHERE is based on the prof. E.A. Chudakov's [1] suggestion to detect the Cherenkov light

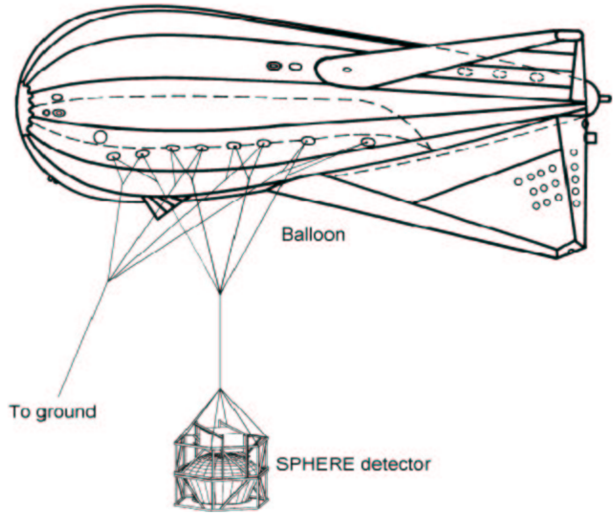


Fig. 1. Experiment configuration for fastened balloon on 1km. altitude

reflected from the snowed surface of the Earth by means of small device lifted above the surface. Cerenkov light of EAS forms a light spot on a snow-covered surface. SPHERE "makes photo" of this spot. Detector lifted to the altitude $H$ make it possible to have sensitive area $\sim H^2$. Elaboration of SPERE detector and the first measurements were carried out in 1975 -2000 years [2, 3, 4, 5, 6, 7].

Further realization of experiment SPHERE is planned in three stages. At the first stage(see Fig.1 ), detector SPHERE-1 (spherical mirror 1.2 m diameter and retina of 19 pixels) will be used for the measurements of the energy spectrum and Cherenkov light lateral distribution function (LDF) of UHE CR in the energy range $10^{16} - 10^{18} eV$ on the base of Russian Antarctic station Novolazarevskaja. Detector will be lifted by the fastened balloon to the height 1 km.

At the second stage the measurements in the energy range $10^{15} - 10^{18} eV$ will be carried out using detector SPHERE-2 lifted by the fastened balloon to level 0.5 - 6 km. The making of this detector begin now.

At the third stage study of the energy spectrum up to above $10^{20} eV$ is planned during long time winter flight around South Pole above Antarctica at height $30 \div 40 km$ (see Fig.2 ). SPHERE-2 make it possible to detect not only Cherenkov light of EAS but fluorescent track of EAS in the atmosphere too [8, 9, 10].

## 2 SPHERE detector

The optical part of array on Fig.3 consists of a $1.2m$ diameter spherical mirror, the mosaic of 19 photomultipliers (PMT) FEU-110 and Shmidt diaphragm for the image correction. At height of lifting $1km$ each of PMT observed the area in diameter $\sim 200m$. The electronic worked in two modes. In the first the trigger condition - was excess of the given threshold level of PMT pulse amplitude simultaneously in any of two PMTs (trigger 2), in the second it was enough excess of a threshold in anyone PMT (trigger 1).

The number of the photons inside $2.0\mu s$ strobe and the pulse duration with step $30ns$ were registered. Control of electronics was carried out in automatic mode with the help of onboard computer. The setup of PMTs high voltage and threshold levels were carried out automatically in dependency of PMTs currents and rate of the events account.

Threshold levels, PMTs current, voltage of accumulators and temperature inside the container with electronics are periodically supervised. Stability of PMT amplification is supervised by periodic submission through fiber of the light pulses

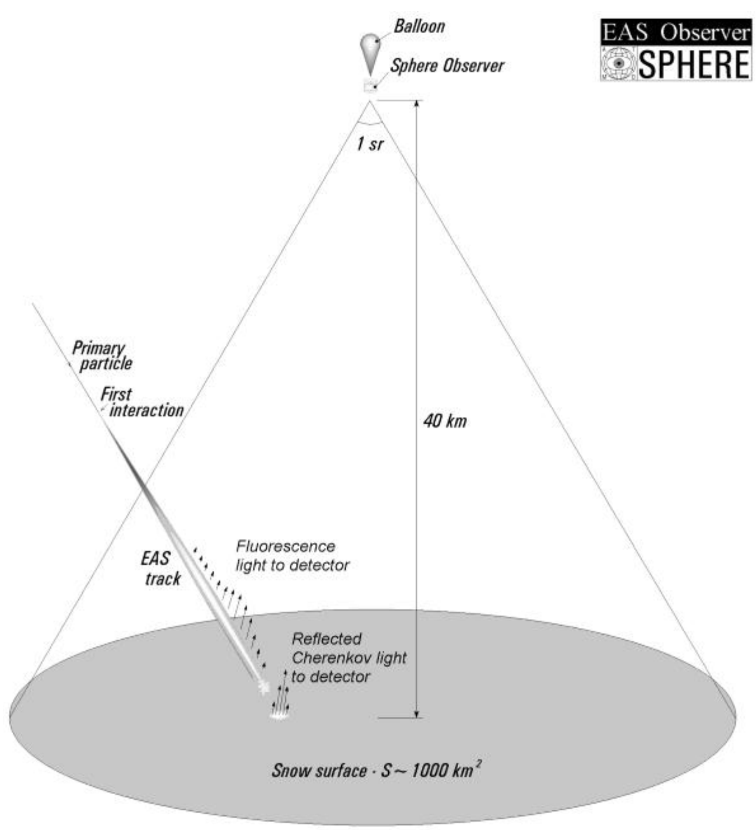


Fig. 2. Experiment configuration of long time antarctic flight.

of various intensity from LEDs on each PMT. The data were accumulated on a hard disk of the computer.

SPHERE array was lifted to height of $H = 1km$. Full time of measurements was $t = 457$ minutes (164 min. at trigger 1 and 293 min. at trigger 2).

When we select the showers which axes are located have got in the central part of area observed mosaic (the greatest pulse located in one of seven central PMTs) the transition from the Cherenkov light registered $Q$ to the primary particle energy ($E_0$) is the most simple:

$$E_0 \sim \frac{Q \cdot 2\pi H^2}{s \cdot K \cdot \eta} ,$$

and differential energy spectrum:

$$I = \frac{\Delta N}{\Delta E} \cdot \frac{1}{\Omega \cdot s \cdot t} , \text{ where}$$

$s = 0.4m^2$ - diaphragm area,

$K$ - light losses (snow surface, PMT's glass, atmosphere, PMTs spaces),

$\eta = 0.18$ - the PMT quantum efficiecy (with shifter),

$\Omega \simeq 1.5sr$ - the effective solid angle for EAS track registered.

$S \simeq 3 \times 10^5 m^2$ - the area observed.

Fig. 4 shows the result such processing in comparison with Tunka experiment [11, 12]. It is no contradiction between these data within the limits of accuracy. One may to see slight hint on the spectrum irregularity.

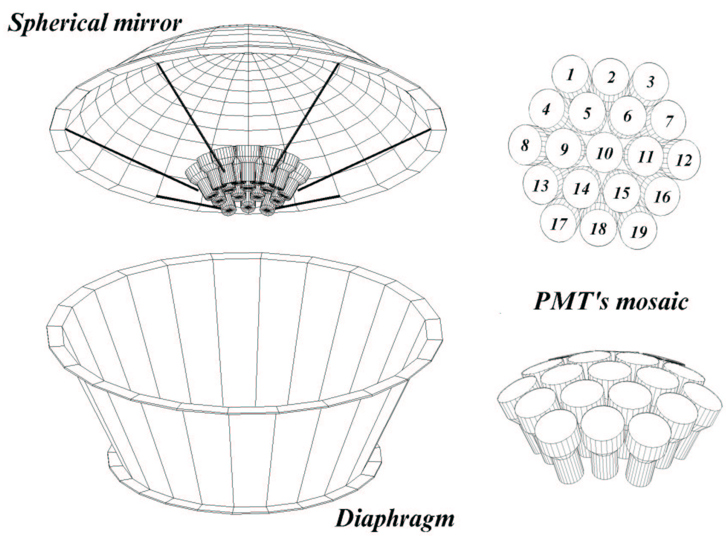


Fig. 3. Optical scheme of SPHERE-1 detector.

In this experiment we attempted to start study of the individual EAS parameters (coordinates of an axis, a direction of arrival, the form of LDF of Cherenkov light). The form of the light stain on PMTs mosaic was used for this purpose (see Fig. 5 ).

19 events from 44 with energy above $3 \times 10^{16} eV$ were selected which axes have got in the central part of the observed area by SPHERE detector (the seven central PMTs). The direction of arrival, position of EAS axis $(x_0, y_0)$ and form LDF were estimated by minimization method. LDF was accepted as:

$$Q(R) = A\left(1 + \frac{R}{R_0}\right)^{-4.3}$$

where $R_0$ - parameter, and $R-$ distance from EAS axis. The estimation of accuracy of measured parameters was carried out on the basis of processing of modelled events. For events with energy $\sim 3 \times 10^{16} eV$ sets of 50 events with zenith angles $\theta-$ 8, 35 and 60 degrees were modelled. The value $R_0$ was accepted equal 200 m. Results of processing are given in the table:

| zenith angle, [grad.] | 8 | 35 | 60 |
|---|---|---|---|
| $\sigma\,\theta$, [grad.] | 7 | 7 | 6 |
| $\sigma\,R_0$, [m] | 10 | 30 | 40 |
| $\sigma\,(x_0, y_0)$, [m] | 5 | 7 | 10 |

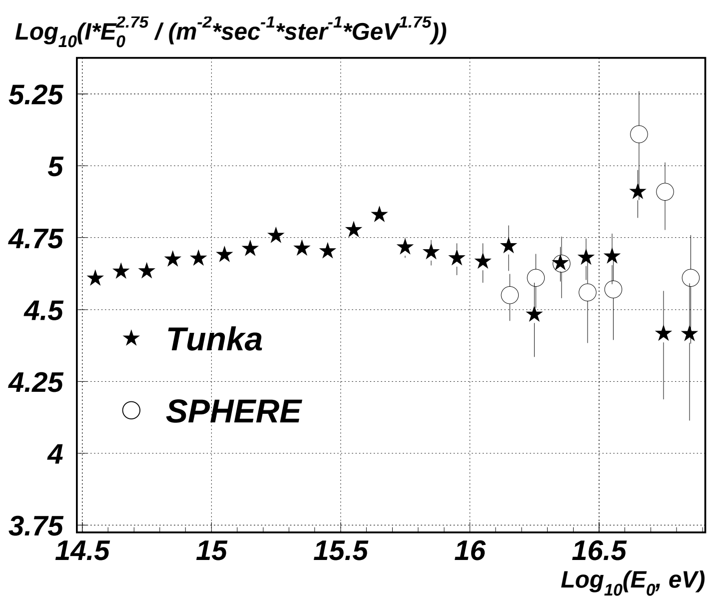


Fig. 4. Energy spectrum primary CR

For the events measured in experiment, average value of a zenith angle was 37 degrees and average value $R_0 - 325m$. The form of average LDF, measured in Yakutsk for EAS with zenith angles from 0 up to 30 degrees [13] in this energy range corresponds to $R_0 \simeq 200m$ and $R_0$ increase with increase of a zenith angle of arrival EAS. So, the received result does not contradict to Yakutsk data.

## 3 SPHERE-2 detector

Fig.6 shows the scheme of detector array. The image of EAS is detected by 100 photomultipliers situated on the focal surface of the spherical mirror of $1.5m$ diameter. Full angle of view is $\sim 1sr$. Detector lifted to the altitude $H$ make it possible to have a sensitive area $\sim H^2$. Each pixel observe the area $\sim 3km \times 3km$ near the Earth surface and $\sim 1.5km \times 1.5km$ for the part of EAS track on the level $15km$. The image of EAS track take place from 1 to $\sim$5 pixels according to the value of track zenith angle. The values and form of PMTs pulses situated along EAS track reflect the EAS casckade curve in the Earth atmosphere. The measurement of PMTs pulse form with diskreteness $\sim 100ns$ make it possible to determine EAS track direction, energy and EAS maximum level in the atmosphere.

It is possible to estimate the values of starlight background PMTs pulses and PMTs pulses caused by the reflected Cherenkov light and by the amount of fluorescent light from the length of EAS track $L \simeq 1km$ in case of mirror with diaphragm area $s = 1m^2$ and EAS energy $E = 10^{20}eV$. $L = 1km$ corresponds to time interval $\sim 3\mu s$.

The mean value of PMTs pulse caused by starlight background will be:

$$n_{bg} = \sqrt{I \cdot s \cdot \omega \cdot t \cdot K \cdot \eta} \cong 30p.e.$$

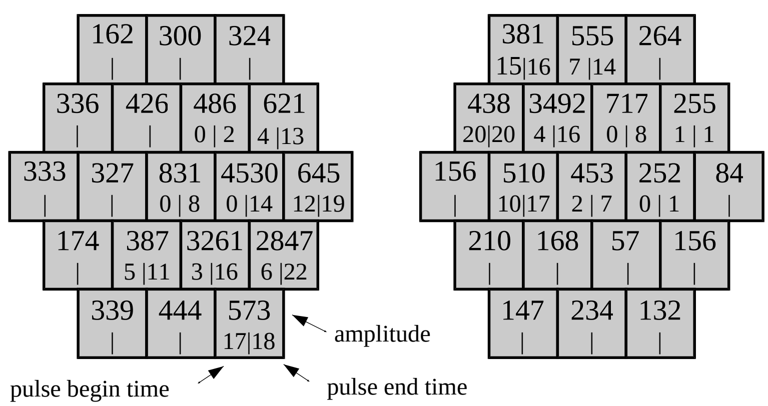


Fig. 5. Example of two registered events. (amplitude in photoelectrons, times in terms of a code $30ns$).

Here $I = 2 \times 10^{11} m^{-2} \cdot s^{-1} \cdot sr^{-1}$ - starlight background, $s$ -area of diaphragm, $\omega = 0.01 sr$ - solid angle for one pixel, $K \cong 0.8$ - light losses under reflection and $\eta \cong 0.18$ - PMT quantum efficiency.

The mean value of PMT pulse caused by the reflected Cherenkov light will be:

$$n_{cher} = \frac{8 \times 10^{-3} \cdot E \cdot K \cdot s \cdot \eta}{2\pi R^2} \cong 21000 p.e.$$

Here $R$ - distance from detector to Earth surfase.

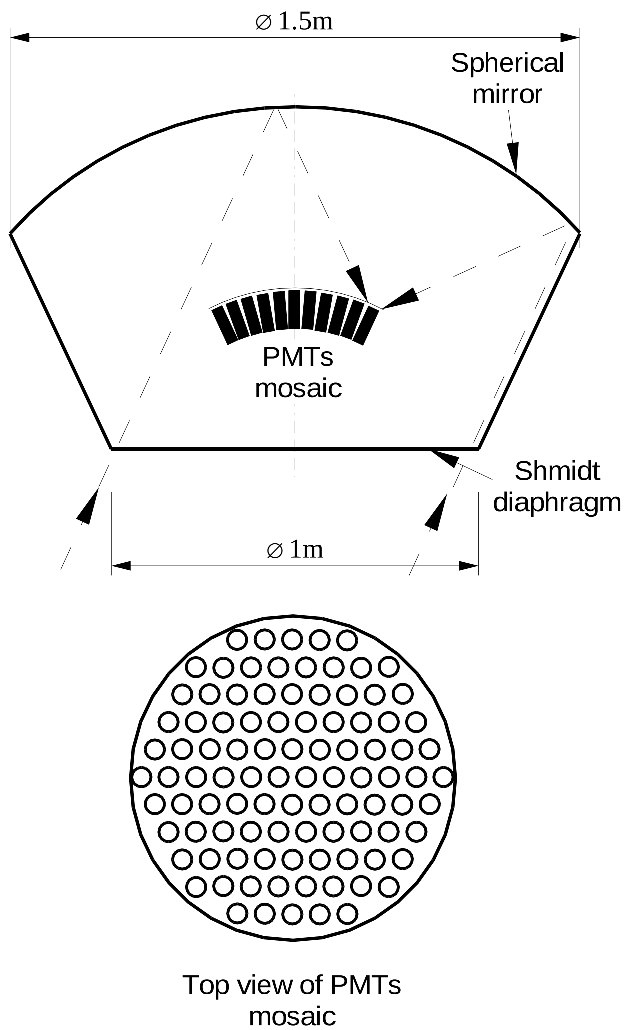


Fig. 6. Optical scheme of SPHERE-2 detector.

The mean value of PMTs pulse caused by the EAS fluorescent light near shower maximum will be:

$$n_{fluor} = \frac{\frac{E}{1.3\times10^9}\cdot 4L\cdot s\cdot\eta}{4\pi R^2} \cong 5000 p.e.$$

These estimations show that the energy threshold will be $\sim 10^{18} eV$.

Expected number of extremly high energy events ($E > 10^{20} eV$) during one long time flight is 20-30 in case of GZK cut off abcence. The reflection cofficient from snow will be measured by means of flash lamp. The power consumed is $\sim 50W$. Weight of array without electrical battary is $\sim 80kg$. Weight of electrical battary is $200 - 300kg$.

## 4 Conclusion

On the first stade we plan to perform the measurements on the base of russian Antarctic station Novo-Lazarevskaya. Experimental array will be lifted by means of fastened balloon to the altitude $1-3km$. The measurements of the EAS Cherenkov light reflected from snow surfase in the energy range $10^{15} - 10^{18} eV$ allow to study energy spectrum and lateral distribution of Cherenkov light. This data will be useful for resolving problem of spectrum knee near $3 \times 10^{15} eV$.

Preliminary processing of the experimental data shows that, as a first approximation, they agree with other experimental data. The further progress in development of this method is connected with the possibility of realization of regular launches of array in more favorable climatic conditions, increase of obseved area and with the further modernization of array. We plan to carry out the next measurements in the Russian Antarctic station Novo-Lazarevskaya. The increase of number of cells in PMTs mosaic up to $\sim 100$ and an opportunity of measurement in each channel of the form of registered pulses will allow to decrease the energy threshold as a minimum in 3 times, to measure within several degrees the direction of EAS arrival and, in variant of measurements with a fastened balloon, to study LDF of EAS in a wide range of distances from an axis. Long time flight on height of $30-40km$ of such array will allow to carry out simultaneous registration Cherenkov and fluorescent light of EAS in the conditions close to orbital and to obtain the data about primary CR in energy range above $10^{20} eV$ [R.A.Antonov et al.(2001)].

There are some serious reasons for carring out such balloon-borne experiment in Antarctida.

It is possible to performance long time (to 100 days) balloon flights around South Pole on the $35 - 40km$ altitude now.

There are not clouds in winter night Antarctida practically and the useful time share may to be about 1 and the value $\Omega$ may to be factor 2-3 more then it for orbital array. The amount of EHECR detected in such flight will differ from it for orbital experiment during 1 year not very much.

The optical system with large angle of view (FOV $\sim 60°$) may to be very simple because the same area resolution will be achieved with factor 100 less number pixels of EAS image.

Two different methods of primary particle energy measurements may be used, the registration of EAS fluorescence light and Cherenkov light reflected from the snow. Simultaneous of these two methods may increase the methodical accuracy of primary particle determination.

The values of EAS light pulses for the same energy in case of balloon experiment are more then in case of orbital experiment by factor $\sim 100$ and the energy threshold about $10^{18} eV$ may be achieved. It will be possible to measure the energy spectrum in the energy range up the GZK cut off and beyond it during one experiment.

The cost of balloon array is some orders less then it for orbital array.

This work was supported by "Russian Foundation for Basic Research" (grants 01-02-16080, 02-03-31004) and by program "Russian Universities - Basic Research" (project YP.02.03.001)

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