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Antarctic Balloon-borne measurements of the CR spectrum above 10^{20} eV (project)

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Abstract. Relatively simple detector SPHERE (spherical mirror $\sim 1.5m^2$ 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 fluorescence track in the atmosphere and the measurement of the full flux of the EAS Cherenkov light.

1 Introduction

There are some great space projects to resolve problem of origin of the Extrmly High Energy Cosmic Rays (OWL - AirWatch [L.Scarsi, 1999]; KLPVE, TUS [S.N.Kuznetsov et al., 2000]). These experimental arrays will consist of optical cameras for the registration of EAS fluorescent tracks in the Earth atmosphere and EAS Cherenkov light reflected from the Earth. The ideas of these methods where proposed by A.E.Chudakov [A.E.Chudakov, 1972], [A.E.Chudakov, 1962]. The operation areas S of such arrays are $10^3 - 10^6 m^2$. At low orbit ($H \sim 400 - 600km$) mirrors of area $\sim 1 - 5m^2$ will allow to detect CR with energy threshold of some units $10^{19}eV$. The value $S \cdot \Omega$ (Ω - effective sold angle of EAS track detected) of such areas will be from some units 10^3 to some units $10^6 m^2 \cdot sr$ and the useful time share will be about 0.1 from full time about 1 year. The cost of such projects may be to 200 millions USD.

D.V.Skobeltsyn Physical Institute of MSU and P.N.Lebedev Physical Institute of RAS work out similar balloon-borne project [R.A.Antonov et al., 2001]. There are some reasons for such balloon-borne experiment. 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 Antarctida practically and the useful time share may to be about 1 and the value Ω 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 (see Fig.1). 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 ~ 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.

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2 Sphere detector array

Fig.2 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 $\sim H^2$. Dark violet filters are used to decrease the influence of the starlight background. 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

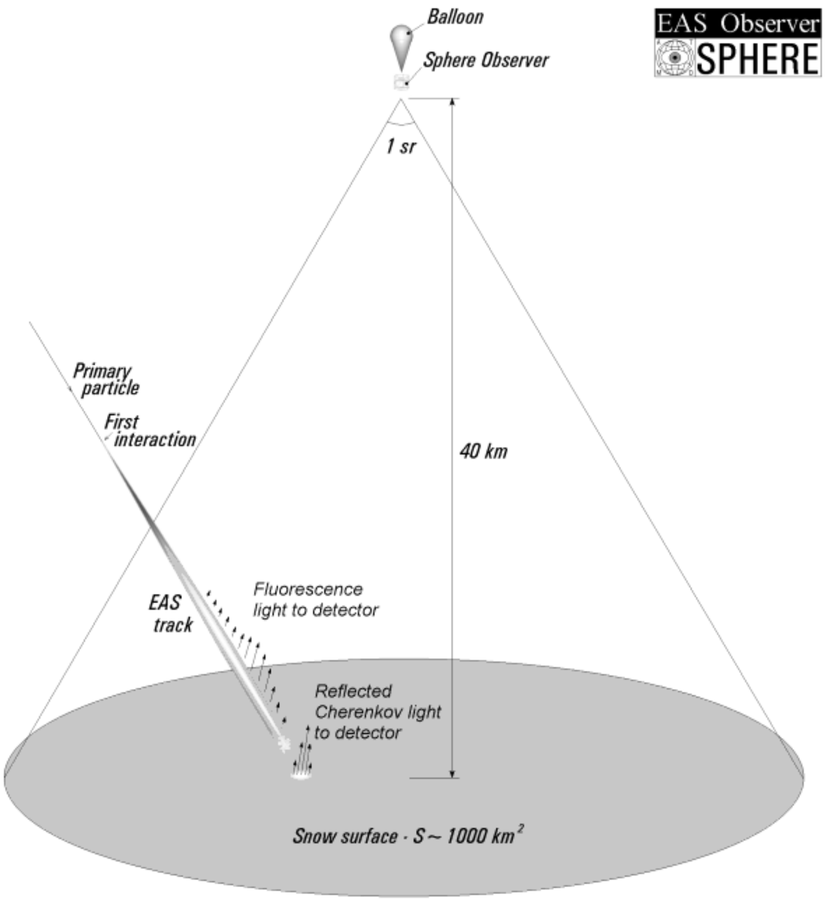

Fig. 1. Experiment configuration.

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:

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

Here $I = 2 \times 10^{11} m^{-2} \cdot s^{-1} \cdot sr^{-1}$ - starlight background, s -area of diaphragm, $\omega = 0.01sr$ - 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:

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

Here R - distance from detector to Earth surfase.

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

$$n_{fluor} = \frac{\frac{E}{1.3 \times 10^9} \cdot 4L \cdot s \cdot \eta}{4\pi R^2} \cong 5000p.e.$$

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

3 Discussion

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 $200 - 300kg$.

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 $3 \times 10^{15}eV$.

We plan the beginning of such Antarctic measurements in 2002 year using more simple variant of SPHERA array. The first methodical measurements with this array were carried out in Tien-Shan mountains and near town Volsk [R. A. Antonov et al., 1997], [R. A. Antonov et al., 1999], [R. A. Antonov et al., 2001].

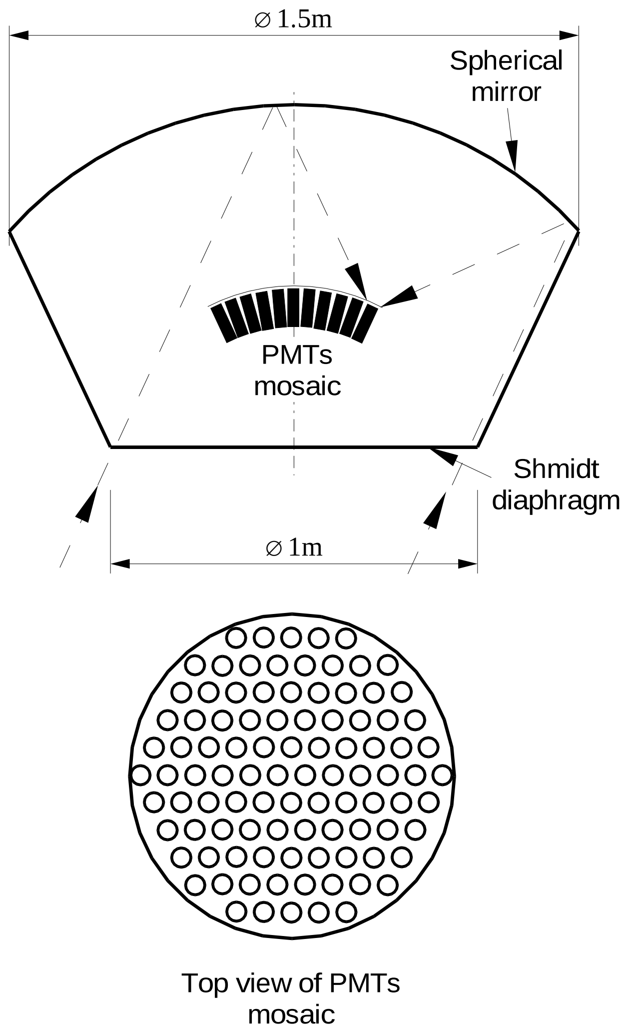

Fig. 2. Optical scheme of SPHERE detector.

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