Balloon Borne Detector for Cosmic Ray Energy Spectrum Measurements and its Possibilities in Connection with AIRWATCH Experiment

R. A. Antonov, D. V. Chernov, A. N. Fedorov, E. E. Korosteleva, M. I. Panasyuk, E. A. Petrova

Institute of Nuclear Physics, Moscow State University, Moscow, Russia

Abstract. The polar balloon–borne experiment to detect atmospheric fluorescence and Cerenkov light of Extensive Air Showers (EAS) may serve as a useful step of preparation of orbital experiment. A small prototype of spacecraft–borne detector is proposed to be used in balloon–borne experiment.

There are some reasons for such a balloon-borne experiment:

1. first of all, it will allow to tie together the data and method of orbital experiment with results of lower energe ground–based experimental arrays;

2. two different methods of primary particle energy measurement, EAS fluorescence and Cherenkov light reflected from the snow detection, can be used in the experiment (see Figure 1);

3. the technique of data preliminary analysis by on-board computer may be optimized in the experiment;

4. real light background value at the atmosphere boundary will be determined experimentally;

5. the protection of light detectors from night–day light conditions changes and local light background sources may be tested in such an experiment;

6. detector for balloon–borne experiment will by some orders cheaper than that for the spacecraft.

Estimated threshold energy of EAS fluorescent track detection for the spacecraft ($H = 500-800$ km) detector is $E_{thr} \sim 10^{19}$ eV for mirror area $S \sim 1 - 3$ m^2 and

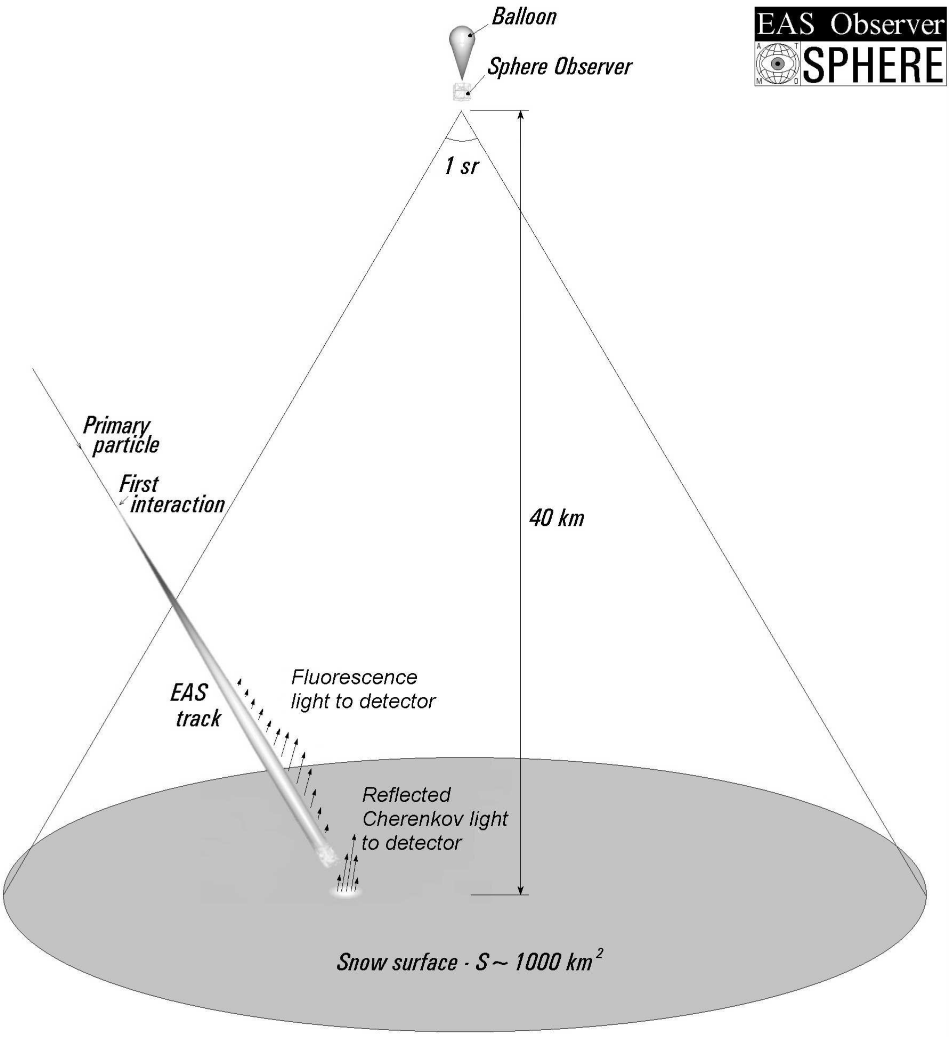

FIGURE 1. Geometry of the free balloon flight around the Pole.

angular resolution of light detector pixel $\omega \sim 10$ mrad. According to

$$E_{thr} \sim H^2 \cdot \sqrt{\frac{\omega^2}{S}}.$$

the same mirror area and angular resolution $\omega \sim 100$ mrad in balloon–borne experiment ($H \sim 40$ km) may ensure threshold energy $E_{thr} \sim 10^{18}$ eV. Threshold energy for Cherenkov detection in balloon experiment should be $E_{Chr} \sim 10^{17}$ eV due to large reflection coefficient of the snow surface (~ 0.9).

The integral flux of fluorescent light as well as the integral flux of Cherenkov light is a good measure of primary particle energy. But due to the anisotropy of Cherenkov radiation the Cherenkov image of EAS is easier to detect than the fluorescent one. Simultaneous using of these two methods might increase the methodical accuracy of primary particle energy determination.

About 150 events of energy $> 10^{19}$ eV may be detected during 20-day polar night balloon flight around Pole at 40 km altitude above the surface.

One needs an array with large number of pixels in the focal plane for a space experiment. To decrease the data flux intelligent data acquisition system is required which selects events of a certain type. Analysing system may include the trigger electronics as well as on–board computer procedure. Its efficiency might be tested and optimized in balloon experiment with small pixel number by transmission of data without selection as well as selected data.

Pixel number might be by $2-3$ order smaller in balloon–borne configuration to provide the same spatial resolution as in spaceship–borne configuration because the balloon altitude is lower by $10-20$ times than spaceship altitude. Simple optics might be used for small light detector number. A spherical mirror of $1-2$ m diameter with corrective diaphragm with the field of view ~ 1 sr ensures 100 mrad angular resolution that implies $60-100$ detectors on the focal plane. Angular resolution of $\omega = 100$ mrad at $30-40$ km altitude corresponds to the $3-4$ km spatial resolution.

EAS track resolution of balloon detector as well as that of spacecraft detector may be improved by each pixel pulse shape detection. It is equal to increasing of pixel number.

Array becomes simple and cheap enough if the number of light detector pixels in mosaic is small $N \sim 10^2$. Electronics may be identical to that of the space detector.

The same array elevated to 1–3 km makes it possible to study primary cosmic ray energy spectrum structure in the region $10^{15} - 10^{17}$ eV and sensitive to cosmic ray composition shape of Cherenkov light lateral distribution function by detecting Cherenkov light, reflected from the snow.

To sum up, suggested balloon–borne detector is characterized by following properties:

1. detector provides the same spatial resolution as in spaceship–borne configuration;
2. detector consists of small pixel number $\sim 10^2$ and simple optics;
3. electronics is identical to the space detector electronics;
4. each pixel pulse shape detection improves the resolution of detector.

SPHERE detector may serve as a prototype of the detector for the balloon-borne AIRWATCH test flight.

SPHERE detector array

SPHERE detector array was elaborated for balloon–borne experiment [1–5]. This work is based on the Prof. A.E. Chudakov's [6] suggestion to detect the Cherenkov

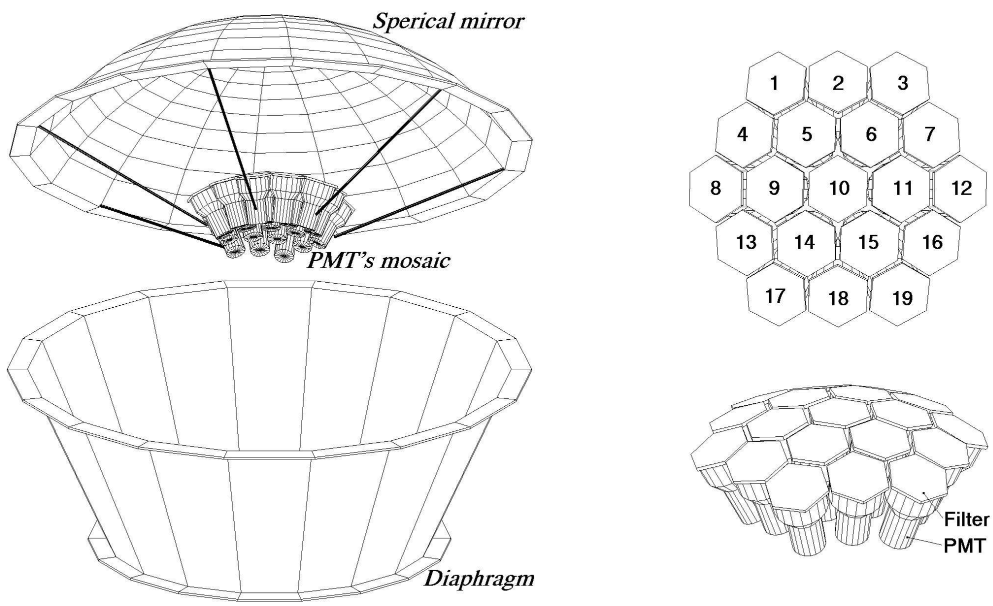

FIGURE 2. 3-D scheme of the optical part of the SPHERE detector.

light reflected from the snow surface.

Figure 2 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 of 1.2 m diameter. 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 $\sim H^2$.

The first measurements were carried out in the Thien–Shan mountains in winter 1993 (Figure 3). SPHERE 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

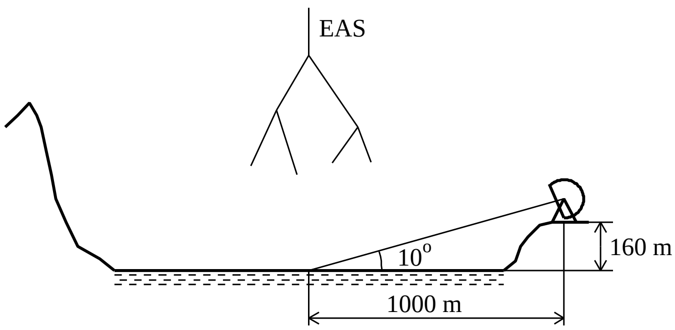

FIGURE 3. Geometry of experiment on B. Alma–Ata lake.

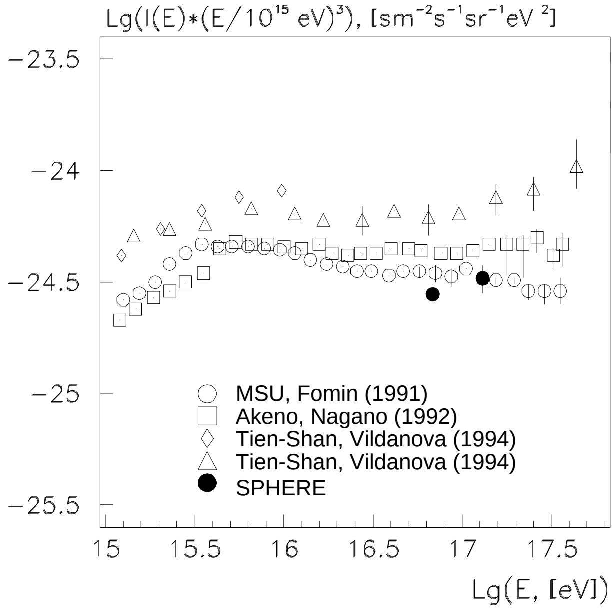

FIGURE 4. The differential energy spectrum.

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.

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

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

During 1994–96 the detector SPHERE was improved significantly.

The amplitude measurements are completed 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 allows to reject events simulated by charged particles in the PMT tubes and filter glass reliably . It makes possible to determine the arrival direction of EAS too.

The electronics for each pixel pulse shape detection is elaborated.

The first methodical lifting of SPHERE detector to 0.9 km altitude by fastened balloon was carried out in winter 1996–1997.

We plan to carry out measurements at altitudes 1–3 km above snow surface using

TABLE 1. Estimation of EAS with $E > E_o$ number to be detected by SPHERE 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	$I(> E_o)$, $(\mathrm{m}^2 \cdot \mathrm{hour} \cdot \mathrm{sr})^{-1}$	E_{thr},eV	$\simeq 10^{15}$	$\simeq 5 \cdot 10^{15}$	$\simeq 5 \cdot 10^{17}$
		t, hour	$\simeq 100$	$\simeq 100$	$\simeq 500$ (20 days)
$1 \cdot 10^{15}$	$5.0 \cdot 10^{-3}$		$1.5 \cdot 10^6$	—	—
$1 \cdot 10^{16}$	$6.5 \cdot 10^{-5}$		$2.0 \cdot 10^4$	$2.0 \cdot 10^5$	—
$1 \cdot 10^{17}$	$6.5 \cdot 10^{-7}$		$2.0 \cdot 10^2$	$2.0 \cdot 10^3$	$1.6 \cdot 10^6$
$1 \cdot 10^{18}$	$6.5 \cdot 10^{-9}$		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

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 SPHERE detector for given flight height H and exposure time t.

1–3 km high balloon–borne experiment is supported by Russian Foundation for Basic Research (grants 95–02–04325a and 96–02–31005k).

REFERENCES

1. Antonov, R.A., et al. *Proc. 14th ICRC*, **9**, 3360 (1975).
2. Antonov, R.A., Ivanenko, I.P. and Kuzmin V.A., *Izvestiya Academii Nauk*, (in Russian), **50**, pp. 2217-2220, (1986).
3. Antonov, R.A., Petrova, E.A., Fedorov A.N., *Vestnik MGU*, ser.3, (in Russian), **36**, 4, pp. 102-105, (1995).
4. Antonov, R.A., Chernov, D.V., Fedorov, A.N., et al. *Nuclear Physics B (Proc. Suppl.)* **52B**, pp. 182-184, (1997).
5. Antonov, R.A., Chernov, D.V., Fedorov, A.N., et al. *Proc. 25 ICRC*, Durban, OG 6.2.11, **4**, 149 (1997).
6. Chudakov, A.E, in *Trudy conf. po cosm. lutcham* (in Russian), pp. 69, Yakutsk, (1972).
7. Fomin Yu.A., et al. *Proc. 22nd ICRC*, **2**, 87 (1991).
8. Nagano M., et al., *J.Phys. G: Nucl.Phys*, **18**, 423, (1992).
9. Vildanova L.I., et al. *Izvestiya Academii Nauk*, (in Russian), **58**, p. 79, (1994).