ISSN 1062-8738, Bulletin of the Russian Academy of Sciences. Physics, 2011, Vol. 75, No. 6, pp. 872–874. © Allerton Press, Inc., 2011.
Original Russian Text © R.A. Antonov, S.P. Besshapov, E.A. Bonvech, V.I. Galkin, T.A. Dzgatdoev, A.S. Petkun, D.A. Podgrudkov, T.M. Roganova, T.I. Sysoeva, Mik. Finger, Mir. Finger, D.V. Chernov, S.B. Shaulov, 2011, published in Izvestiya Rossiiskoi Akademii Nauk. Seriya Fizicheskaya, 2011, Vol. 75, No. 6, pp. 923–925.

The SPHERE Experiment: Baikal 2010

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Abstract—The SPHERE-2 detector was lifted above the snow-covered surface of Lake Baikal by a captive balloon several times in 2010. The Vavilov–Cherenkov radiation of extensive air showers was measured. Preliminary results from processing the data of the SPHERE-2 experiment at various altitudes of observation are presented.

DOI: 10.3103/S1062873811030087

INTRODUCTION

The SPHERE experiment is one stage in the development of a new method for studying EASes based on the ideas of A. E. Chudakov [1]. The experimental SPHERE-2 unit [2–5] is an optical system consisting of a spherical mirror of 1.5 m in diameter with an adjustable diaphragm and a mosaic of 109 photomultipliers (PMs) mounted on the focal surface of the mirror. On moonless nights, the unit is lifted to 1 km above the snow-covered surface of Lake Baikal to register the EAS Cherenkov light reflected from the snow.

EXPERIMENTAL

Controlling the Unit's Operation

In March 2010, SPHERE-2 was lifted seven times by a captive balloon above the ice- and snow-covered surface of Lake Baikal. EAS Cherenkov light was measured six out of the seven times.

The performance parameters were monitored during the operation of the array. The level of PM anode currents in particular was constantly checked during each flight, as this parameter contained data on the PM gain rate k_{pm}, the atmospheric transparency, and the reflectivity of the snowy surface:

$$i_{\mathrm{pm}} = k_{\mathrm{pm}} IS\Omega\eta K 1.6 \times 10^{-19},$$

where $I = 5 \times 10^{12}$ photon m^{-2} s^{-1} sr^{-1} is the light bias of the starry sky, $S = 0.465^2\pi - 0.245^2\pi \approx 0.49$ m^2 is the active area of the mirror, $\Omega = 2 \times 10^{-3}$ sr is the bodily angle of observation of each PM (the full angle of PM observation $\varphi = 28$ mm/525 mm $= 0.053$ rad $=$ 3.05 grad), $\eta = 0.1$ is the quantum efficiency of the PM photocathode, and $K \approx 0.8 \times 0.8$ is a factor that allows for reflections from the snowy surface and the mirror.

If gain rate k_{pm} is close to 10^5, PM anode current i_{pm} will be about 5 μA.

The current for each PM was measured once a minute during the experiment. According to the results of direct measurements, current i_{pm} for different PMs was 2–4 μA. The current became slightly more intense at the end of every session, i.e., at the break of dawn.

One condition for triggering the unit is that the amplitude exceed the threshold impulse (V_{thresh}) in three adjacent photomultipliers in the mosaic. Threshold V_{thresh} corresponds to 5σ, where σ is the level of fluctuation in a PM photocathode over 25 ns. The fluctuation of the current is determined as $\sigma = (IS\Omega\eta K 25 \times 10^{-9})^{0.5} \approx 3$ ph. e. Then $V_{\mathrm{thresh}} \approx 5 \times 10^{-3}$ V, which corresponds to 2.5 units of the system registration code.

According to our estimates and the rated spatial distribution functions of EAS Cherenkov light (SDFs of CL) [6], the form of the SDF of EAS CL with an energy of 10 pEv can be studied at up to 200 m from an EAS if the SPHERE-2 unit is lifted 1 km above the surface of the snow and $V_{\mathrm{thresh}} > 5$ mV.

After the unit has been lifted to the programmed altitude, the response thresholds in all of the measurement channels are adjusted automatically so that the events dictated by the background of the starry sky are recorded at a rate of 10 Hz in each channel. The number of responses in each measurement channel is established every 10 min during the flight. The spread of these values characterizes the accuracy with which the threshold response is set for the channels in which pulses are registered.

Exposure durations for the SPHERE-2 unit at various heights in 2010

Altitude of the unit, m	900	700	500	380
Duration of exposure, min	940	210	195	405

MEASUREMENT RESULTS

The table below presents data on the duration of measurements and the altitude of the unit over the surface of Lake Baikal (455 m above sea level). In the 29 h of measurement, 1343 trigger responses were registered.

For provisional analysis of the registered events, we used a graphic interpretation similar to the one presented in Fig. 1. The curve represents oscillograms for 95 measurement channels. The channels are numbered along the horizontal axis, while the relative time is given along the vertical axis. Each rectangle denotes a single measurement of the AD converter with an interval of 25 ns. The rectangle is colored in proportion to the pulse amplitude, with black denoting the peak amplitude of the event. It can be seen from the figure that in such a representation of the oscillograms, the time intervals with the highest pulse amplitudes form a complex sinusoid. This effect is possible due to the mutual arrangement of channels in the mosaic of the light sensor also shown in Fig. 1. Every subsequent period of the aforesaid curve corresponds to the measurement channels of the photomultipliers, which are arranged in the form of another ring on the surface of the light sensor. The amplitude (along the axis of time) for each period of the curve depends on the zenith angle of the EAS axis. The shift in the curve phase shows the azimuth angle of the EAS axis. The black rectangles show the area near the EAS axis.

The above method of analysis is used for the provisional qualitative evaluation of EAS parameters, and

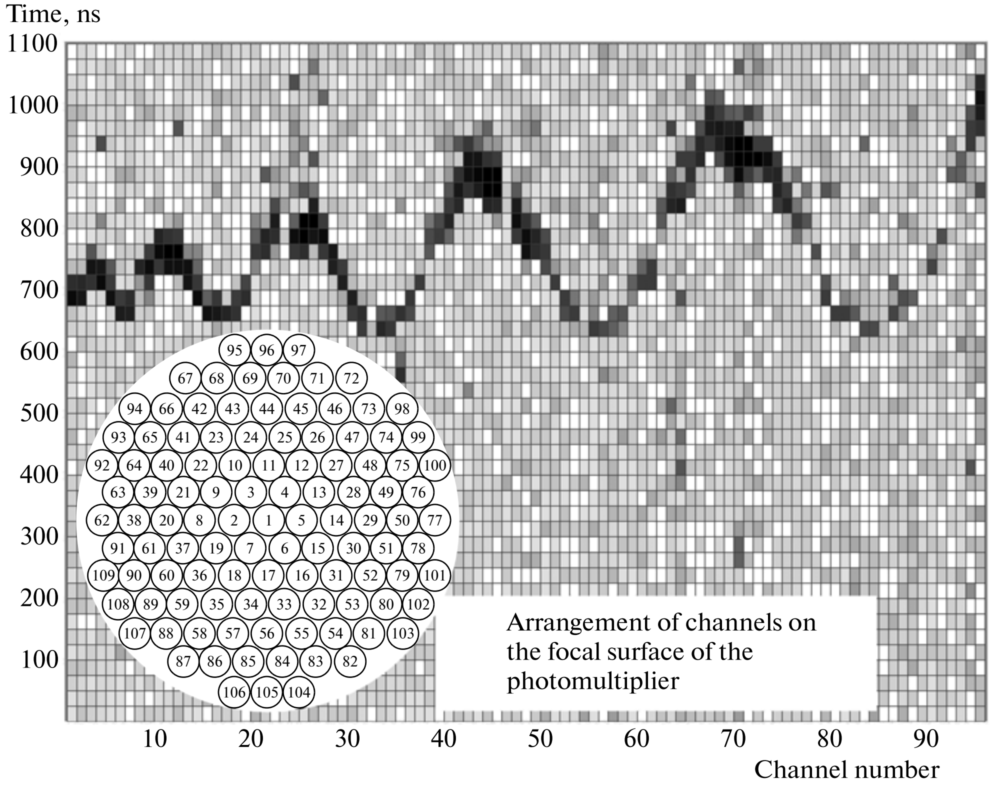

Fig. 1. Sample presentation of an experimental event. The measurement channels are numbered along the horizontal axis, and the relative time is marked along the vertical axis. Each rectangle indicates a single measurement of the AD converter with a gap of 25 ns. The color of the rectangle stands in proportion to the pulse amplitude, with black indicating the peak amplitude of the event. The circles show how the numbers of the channels are arranged in the PM mosaic.

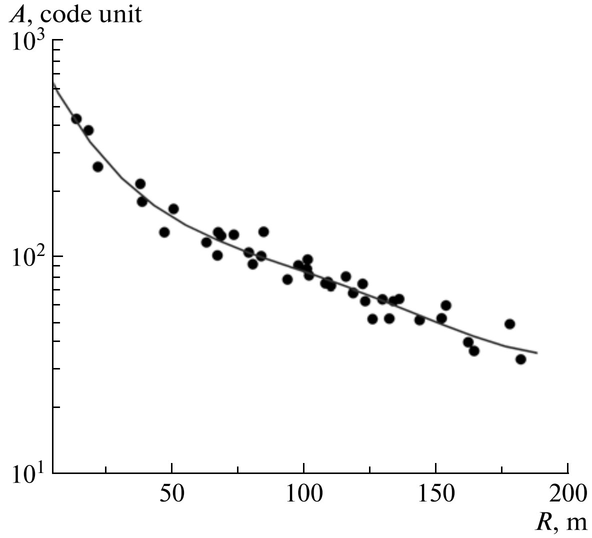

Fig. 2. Sample SDF of CL from an event registered with the SPHERE-2 detector. $E_0 \sim 2 \times 10^{16}$ eV, $\Theta \sim 19°$. The balloon was lifted 380 m above the surface of the lake. The block curve results from our approximation of the observed data.

as a performance characteristic of the measurement devices.

The EAS parameters can be determined more accurately if the variable method in [6] is used. The EAS axis lies in the assumed flat front of EAS Cherenkov light. In Fig. 2, we can see a plot of the spatial distribution of EAS CL for the event described above. The graph shows that a high spatial resolution is attained at low altitudes. The distance between the EAS axis and the nearest point is only 15 m. The visual field of the PM corresponding to the given point overlaps the area where the EAS axis meets the surface of the lake. Most ground-based installations cannot be used to measure the intensity of CL near the EAS axis, although registration of these values could help solve the problem of determining the chemical composition of the original ultra-high energy cosmic rays.

CONCLUSIONS

A series of measurements of EAS Cherenkov light was performed using the SPHERE-2 balloon. The SDFs of the showers registered by the SPHERE-2 installation in March 2010 were reconstructed. The processing of the observed data is in progress.

ACKNOWLEDGMENTS

This work was supported by the basic research program “Neutrino Physics and Astrophysics” of the Presidium of the Russian Academy of Sciences.

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