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ФИЗИКА И ТЕХНИКА УСКОРИТЕЛЕЙ

GROUND-BASED COMPLEX FOR CHECKING THE OPTICAL SYSTEM OF THE TUS EXPERIMENT

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The purpose of TUS space experiment is to study ultrahigh energy cosmic rays produced by extensive air showers from space. The concentrator is located on satellite, made in the form of the Fresnel mirror towards the Earth's atmosphere, the focus of which is a photodetector. The angle of view of the mirror is $\pm 4.5^\circ$ which for a given height of the orbit corresponds to the area 80×80 km on ground. The ground complex, consisting of a number of stations, to check the optical system of the experiment is created (their location and the amount will be determined after the launch of the satellite based on its actual orbit).

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INTRODUCTION

The TUS mission is a satellite mission for the experimental study of ultrahigh energy cosmic rays (UHECR). The fluorescence and Cherenkov UV yield of Extensive Air Showers (EAS) generated by UHECR particles will be detected at the night side of the Earth atmosphere from the orbital space platform at altitudes in the 400–500 km range. This will allow for the measurement of the CR spectrum, composition and arrival directions at $E > 7 \cdot 10^{19}$ eV [1, 2] beyond the GZK energy limit.

As one can see in Fig. 1, the TUS UV telescope has two main components: a modular Fresnel mirror and a 16×16 pixels photo-receiver matrix with the corresponding DAQ electronics [3]. The Fresnel mirror has an area of 1.8 m^2 and a focal distance of 1.5 m, each pixel of the photo-receiver consists of a 13-mm-diameter multi-alcali cathode Hamamatsu R1463 PMT with UV glass window, and the DAQ electronics has 256 separate channels with a time resolution of 0.8 μs per channel. The TUS UV telescope has a total FoV of $\pm 4.5^\circ$, with an FoV per pixel of ~ 0.1 mrad corresponding to a spatial resolution of 5×5 km on the Earth surface for an orbit height of 500 km.

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Fig. 1. The TUS detector aboard the Lomonosov satellite

At present, the production phase of the TUS UV telescope has been completed, and the telescope is currently undergoing pre-fight tests. The TUS mission is scheduled for launch at the end of 2015 aboard the dedicated Lomonosov satellite, and is expected to operate for 3–5 years [4]. This will be the first orbital mission for the study of the UV fluorescence yield of EASs produced by UHECR, and atmospheric effects aside, it will allow for a more stable study of EASs than ground-based observations. Moreover, it is extremely important to emphasize that since the TUS mission will provide a systematic and more uniform coverage of both the northern and southern hemispheres, it will also allow for the possibility to better understand the differences between the results of the Pierre Auger Observatory in the southern hemisphere and those of the TA in the northern hemisphere.

However, as the EAS UV photon flux reaching the orbital TUS telescope is ~ 100 times weaker than the corresponding flux available to ground-based observatories, the issue of calibrating the telescope in the presence of night-sky background is critical. Under these circumstances, regular monitoring and calibration of the orbital telescope is needed during the entire lifetime of the TUS mission, in order to ensure the accuracy and reliability of the data. For this purpose, dedicated high-power LED source will be used at appropriately chosen locations on the ground to provide periodic calibration signals to the orbital telescope. The evaluation of the operational characteristics of these light sources constitutes the topic of the present work, and our approach and results will be presented in the following sections.

1. CALIBRATION METHOD

In this section, we present the ground-based calibration methods that are currently under development for the TUS mission. This method relies on the use of ground-based light source illuminating the TUS telescope while in orbit to allow for the testing and correction of the telescope photo-detector and associated electronics calibration parameters on a regular basis.

In this method, a light beam generated by high-power LED system is shot vertically in the FoV of the TUS telescope, directly illuminating its pixels. In this way, the image of the calibration source can cross up to 16 adjacent telescope pixels in one calibration run.

The calibration source parameters were evaluated based on Monte Carlo simulations of the TUS telescope that account for the optical system and trigger electronics characteristics [5–9]:

1) light pulse duration $\geqslant 40$ μs;
2) the pulse energy 10–50 mJ ($1.9 \cdot 10^{16}$–$9.6 \cdot 10^{17}$ photons);
3) the spectral interval 300–400 nm;
4) the pulse frequency 0.5–10 Hz;
5) angular divergence of light beam $\pm 4.5°$;
6) intensity of light flux at the 500 km latitude 100–500 $\mathrm{m}^{-2} \cdot \mu\mathrm{s}^{-1}$);
7) duration time of the calibration session 10–100 s;
8) long-term stability of light source 1–3%.

2. LED PROTOTYPE SOURCE FOR THE TUS TELESCOPE CALIBRATION

The design and fabrication of prototype LED sources for the TUS telescope calibration through direct and indirect illumination is presently under way both at JINR and at ISS. The LED of choice for the development of the light source is the LedEngin Inc. LZ4-00U600 LED [10]. It is a compact 7×7 mm high-power UV LED (1.1 W optical output power), with the optical output spectrum confined to a narrow band around $\lambda = 365$ nm and with an integrated glass lens, which makes it an ideal candidate for a calibration light source for the ground-based calibration of the TUS telescope.

The angular distribution of the LED optical output power is illustrated in Fig. 2.

As is immediately obvious from this figure, despite the integrated lens the output light flux is exceedingly wide and in this configuration, about 80% of the optical output power would be lost for the purpose of calibration. The solution to this problem, imposed by the cooling requirements for the LED (see Fig. 3), is to use additional collimation lens to reduce the angular width of the light flux to a value corresponding to $\pm 4.5°$ FoV of the orbital TUS telescope.

A system for focusing quartz glass lenses made with different radii of curvature was developed to obtain the necessary angle of view. The calculation was based on the ratios

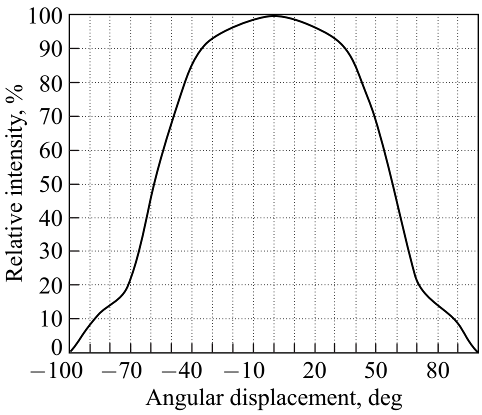

Fig. 2. The angular distribution of the LED optical output power

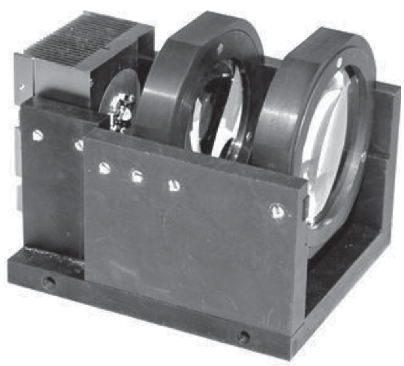

Fig. 3. LedEngin-LZ4-00U600 LED with air cooler and the optical system

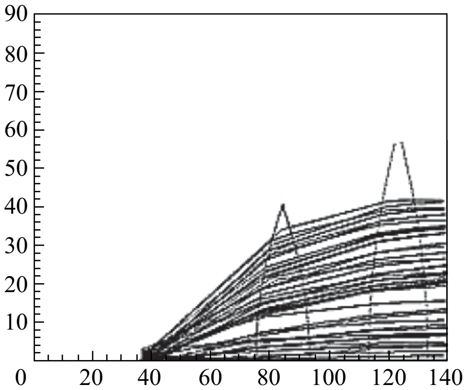

Fig. 4. Paths of rays for the system of 2 lenses

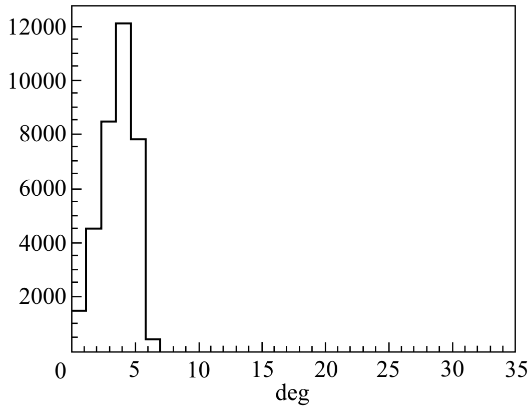

Fig. 5. The divergence of the output light beam

$(n-1)(1/R_1 - 1/R_2) = 1/F$, where n is the refractive index, R is the radius of curvature of the lens surface and F is focal length.

Paths of rays for the system of 2 lenses with allowance for the size of the source are shown in Fig. 4.

Figure 5 shows the results of Monte Carlo simulation of the divergence of the output light beam from the optical system. It is shown that the optical system produces a beam of light with a divergence of $\pm 4.5°$.

The electronic part of the calibration system consists of a GPS/GLONAS receiver, microcontroller and LED driver. The microcontroller generates a temporal sequence of light signals, the required duration and synchronizes them with the time tags produced by the GPS/GLONAS receiver. The pulse duration is 50 μs, and repetition frequency is 1.6 Hz. The duration of the calibration session is 20 s.

CONCLUSIONS

The TUS mission aboard the dedicated Lomonosov satellite will be the first mission to use an orbital UV telescope for the study of EASs produced by UHECR. As such, it will provide important information and data for similar future missions such as Mini-EUSO, JEM-EUSO and KLYPVE. During its 3–5 years operation, the exposure of the TUS telescope will be 12000–20000 km^2· sr, which is comparable with the exposure of the largest ground-based detectors. The ground-based calibration method presented here is based on the use of high-power LEDs, and prototypes of the latter are currently under development.

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