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Development of an image analysis technique for mirrors monitoring of the TAIGA-IACT

© *A.D. Ivanova,*[1,2] *D.P. Zhurov*[1,3]

[1]Institute of Applied Physics, Irkutsk State University,
664003 Irkutsk, Russia
[2]Moscow Institute of Physics and Technology (National Research University),
141701 Dolgoprudny, Moscow Region, Russia
[3]Irkutsk National Research Technical University,
664074 Irkutsk, Russia
e-mail: 2013sasha68@gmail.com

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The paper presents a description of the developed technique for monitoring of the mirror positions of the Imaging Atmospheric Cherenkov telescopes based on the Bokeh method. The telescopes are part of the experimental complex TAIGA, located in the Tunka valley (Republic of Buryatia, Russia), 50 km from Lake Baikal. The results of the analysis of CCD-camera images to determine the position of mirror segments are presented.

Keywords: TAIGA-IACT, Bokeh method, gamma astronomy, mirror monitoring.

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Introduction

The astrophysical complex TAIGA (Tunka Advanced Instrument for cosmic rays physics and Gamma Astronomy) [1] is designed to conduct research in the field of cosmic ray physics and gamma-ray astronomy by the method of recording extensive air showers (EAS). A hybrid approach to the study of primary cosmic radiation, which combines facilities with detectors of different types into a single system, is a unique feature of the complex. At present, it consists of a wide-field TAIGA-HiSCORE [2] facility, a TAIGA-Muon [3] scintillation facility, and three TAIGA-IACT [4] Atmospheric Cherenkov telescopes (ACTs). The main tasks of the complex include: the study of the energy spectrum and mass composition of cosmic rays in the energy range of 100 TeV − 1000 PeV, the search for diffuse gamma radiation over 100 TeV and the study of local sources of gamma-quanta with energies of more than 5 TeV.

1. TAIGA-IACT Telescopes

The telescopes of the TAIGA-IACT installation have an alt-azimuth mount and consist of a segmented mirror of the Davis-Cotton design and a recording chamber based on photomultipliers (PMT) (Fig. 1).

To control the position of the telescope during observations, a CCD camera is installed on the telescope plate, and to eliminate frost on the mirrors in winter — a mirror heating system. The reflector consists of individual spherical mirrors with a diameter of 60 cm and has a total reflective surface area of $9.5\,\mathrm{m}^2$. The focal length of the telescope is 4.75 m. The Cherenkov camera provides an angular view of $9.6 \times 9.6^\circ$ and includes ~ 600 PMT (pixels). Each pixel has an angular size of 0.36°, an inlet hole of 30 mm, an output of — 15 mm, and is equipped with a Winston cone that increases the light collection area by approximately 4 times. A more detailed description of the telescope's camera and its characteristics can be found in the paper [5].

ACTs recordings record an image of Cherenkov radiation generated by cascades of relativistic charged particles arising from the interaction of primary cosmic radiation with the nuclei of atoms in the atmosphere. In order to obtain a clear image in the ACTs cameras and the subsequent correct assessment of the EAS parameters and the type of the primary particle, it is extremely important to use the correctly tuned optics of the telescope and monitor its condition.

2. Using the Bokeh Method

Experimental data, on the basis of which the mirror monitoring technique was developed and tested, were obtained using the Bokeh method [6]. The Bokeh method consists of placing a light source at a short distance from the telescope, and images of each segment of the reflector are visible on an out-of-focus screen. The main advantage of this method compared to others [7,8] is the availability of information about individual mirrors, as well as the ability to take measurements in early twilight. The experimental data collection procedure consists of several steps. In the first, the telescope is pointed at a light source. Then, with the help of a specially designed screen, which is not in the focus of the telescope and is placed on the front side of the Cherenkov camera, images of mirrors are recorded. On the telescope plate there is a Prosilica GT1380 CCD camera, which is installed in such a way that the entire Cherenkov

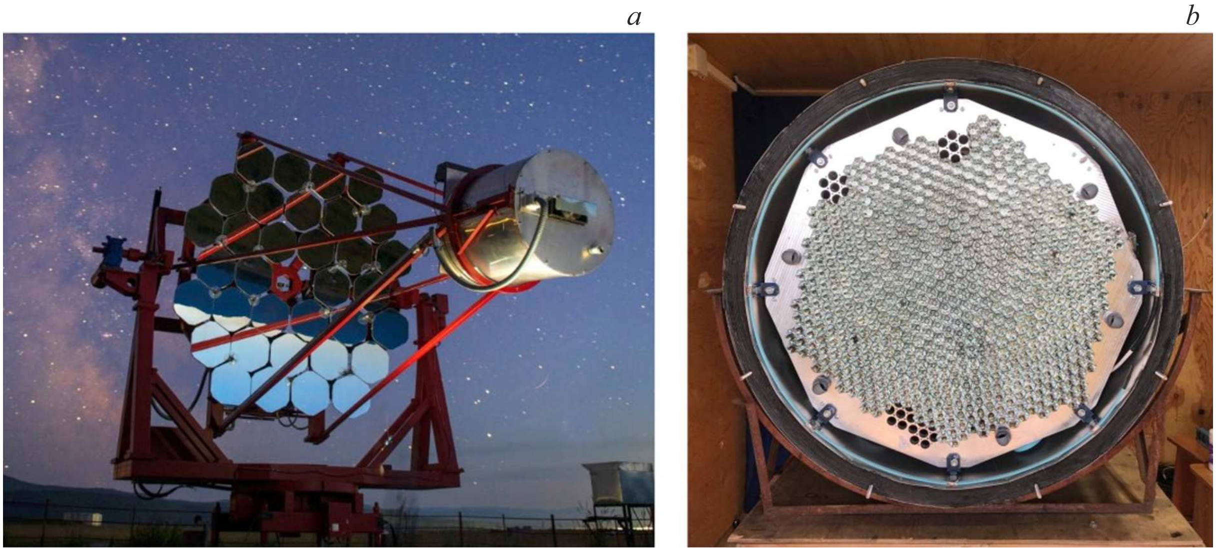

Figure 1. Images of the second ACT of the TAIGA-IACT (*a*) and the Cherenkov camera (*b*).

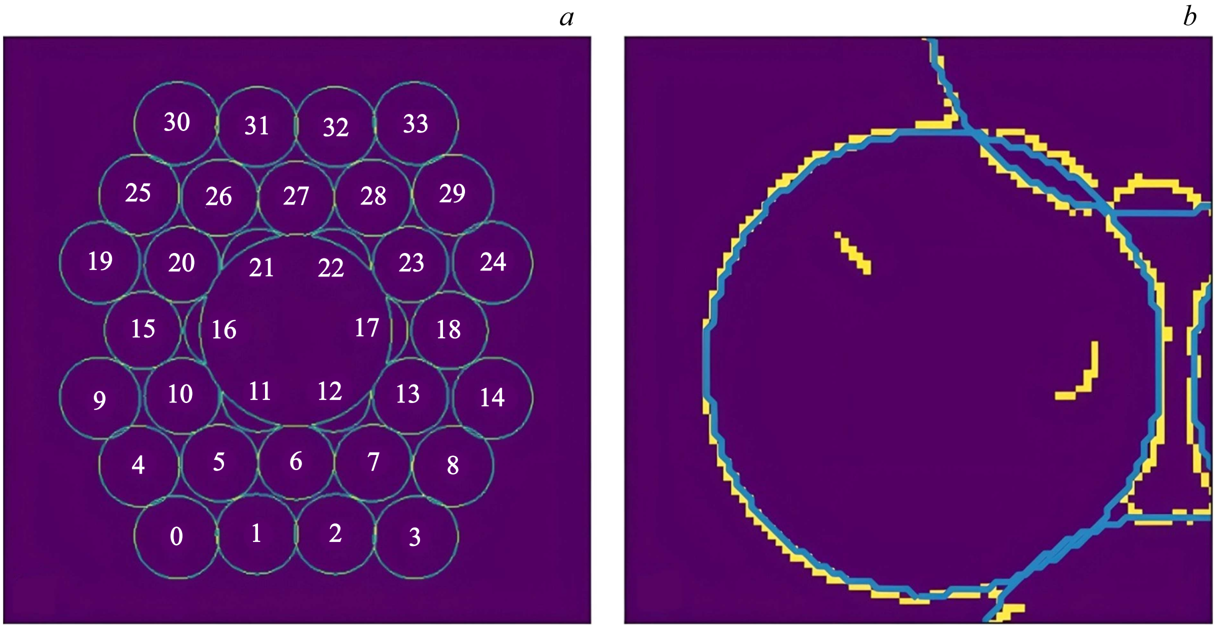

Figure 2. *a* — image of mirror contours obtained as a result of computer simulations; *b* – the contour of the 9th segment of the mirrors, obtained from the CCD camera (in yellow (in the online version)) and calculated from the simulation with corrections (in blue (in the online version)).

camera falls into the field of view. The experimental data are the images obtained by the CCD camera at different directions of the telescope (for the alignment of the central mirrors, due to their shading by the Cherenkov camera, the telescope was lowered and raised 4° from the direction to the source).

3. Mirror Monitoring Procedure

A pattern of the exact position of the mirrors was obtained using computer simulations [9] and is shown in Fig. 2, *a*. The program considers all the parameters of the TAIGA-IACT installation: the size of the mirrors, the location of the focal plane for each telescope, the placement of the light source, and the number of photons. The program that detects mirror offsets involves applying a perfect template to the CCD image from which the contours are extracted. Further, the shift of the actual position of the mirror compared to the template is determined. Fig. 2, *b* shows the contour of the mirror from the CCD-camera, its selected contours, as well as the contour calculated using computer simulation with corrections obtained by numerical

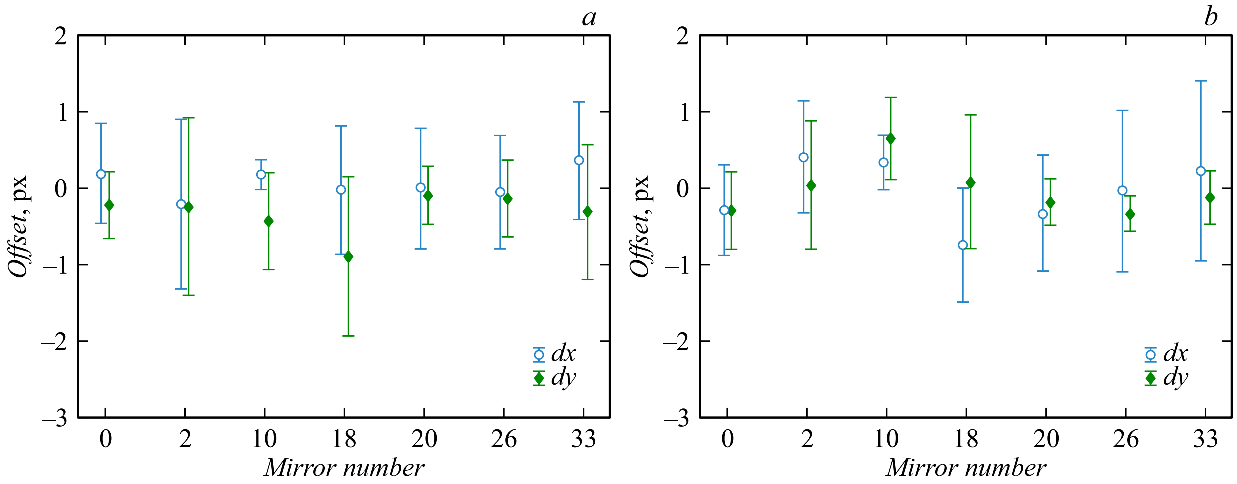

Figure 3. Average values of offsets at two coordinates for January (*a*) and February (*b*) 2023 relative to December 2022

methods. The corrections are calculated on the basis of reference measurements with correctly aligned optics and are necessary due to the fact that the simulation does not consider the real small shifts in the positions of the mirrors relative to the ideal configuration.

To test the mirror monitoring technique, images from December 2022, January and February 2023 were analyzed, which contain data from five different telescope angles of three images each. Fig. 3 shows the average values of the two-coordinate offsets for the seven mirrors selected from different sides on the telescope plate for January and February 2023 compared to December 2022. In all cases, the measurement error is within the size of one pixel, and the displacements within two months do not exceed the measurement errors.

Conclusion

In the course of the work, a method for monitoring the position of mirrors from an image from a CCD camera using the Bokeh method on TAIGA-IACT telescopes was developed. A number of measurements and analysis of experimental data were carried out to assess the displacements of the mirror directions. In future, it is planned to use the obtained procedure for monitoring the shift of mirrors on all telescopes of the TAIGA-IACT installation in order to adjust them in a timely manner and study the causes of deviations.

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Conflict of interest

The authors declare that they have no conflict of interest.

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