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TAIGA: A Complex of Hybrid Systems of Cooperating Detectors for Gamma Astronomy and Cosmic Ray Physics in the Tunka Valley

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Abstract—The relevance and benefits of the new TAIGA gamma observatory complex in the Tunka Valley (50 km from Lake Baikal) are discussed. The main aim of the TAIGA installation is to study high-energy gamma radiation and search for cosmic pevatrons. The first series of gamma stations was commissioned in 2019 and covers an area of 1 km^2. Its expected integral gamma radiation sensitivity at an energy of 100 TeV over 300 h of source monitoring is (2–5) $\times$ 10^{-13} TeV cm^{-2} s^{-1}. It is planned to expand the effective area of TAIGA gamma observation to 10 km^2 in the future.

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INTRODUCTION

The most important results in high-energy gamma astronomy have been obtained using installations composed of so-called Imaging Atmospheric Cherenkov Telescopes (IACTs). Each installation includes from 2 to 5 IACTs with composite mirror diameters of 4 to 28 m, along with multichannel cameras for recording Cherenkov radiation patterns of extensive air showers (EASes). To reconstruct EAS parameters and establish the origin of the generating particle, EASes must be captured by several IACTs (the stereo-

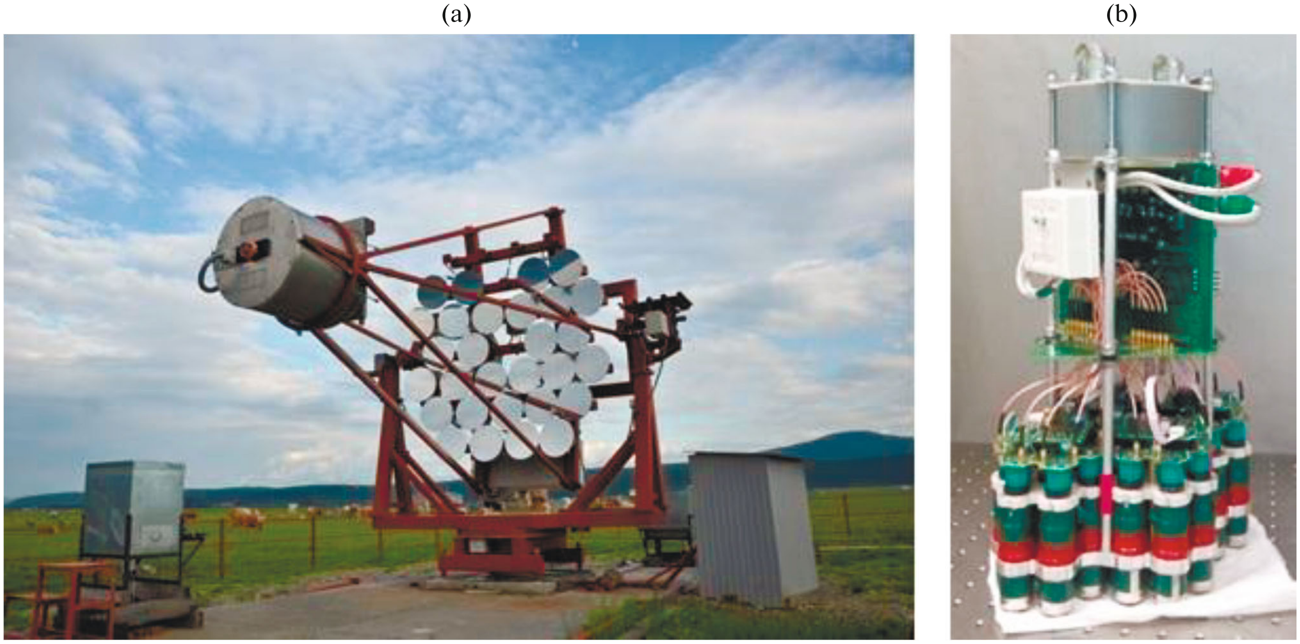

Fig. 1. (a) The first IACT of the TAIGA observatory; (b) PMT cluster of the IACT camera as part of the TAIGA–IACT complex.

scopic mode). IACTs are therefore spaced from one another at distances of about 100 m. The high cost of IACT-based setups, the areas of which are as large as the several kilometers needed for high-energy gamma-radiation studies, is holding back the creation of such systems.

An approach has been developed in recent years for studying ultrahigh-energy gamma rays in the project to create the TAIGA (Tunka Advanced Instrument for Gamma Astronomy) gamma observation facility 50 km from Lake Baikal with a hybrid system of cooperating detectors. Its main feature is that the precision determination of the energy, position, and direction of an EAS axis is based on the spatiotemporal characteristics of EAS Cherenkov pulses, measured with a network of TAIGA–HiSCORE broad-angle detectors [1]. When these are known, we can distinguish gamma quanta from the hadron background with only one IACT (i.e., in the single mode). The distance between the expensive IACTs can therefore be increased to at least 600 m, and even to 1000 m.

THE TAIGA–HISCORE BROAD-ANGLE CHERENKOV FACILITY

Each optical TAIGA–HiSCORE station has two containers. The first of these (Cherenkov-type) contains four photoelectron multipliers (PMTs) with photocathode diameters of 20 or 25 cm (ET9352KB, R5912, and R7081). Each PMT is equipped with a Winston cone made of mirror material, allowing the effective area of light collection to be increased by 4 times. The viewing angle of each cone is $\pm 30°$ ($\sim$0.6 sr). Analogous signals from the anodes and the fifth dinode of each PMT are transmitted to the second electron container placed next to it (to expand the dynamic range), where they are summed, digitized, and preliminarily selected according to specified criteria. The data acquisition system of the TAIGA–HiSCORE setup has a hierarchic structure. The optical stations are divided into clusters composed of around 30 substations. The data acquisition system of each cluster has two levels. The first is electronic elements for collecting data from the optical stations, which are stored in thermally stable containers near the Cherenkov containers. The second is the central electronic system of the cluster positioned at its geometrical center. Each optical station is connected to the cluster's central electronic system by an optical cable, through which data transfer and synchronization occur with subnanosecond accuracy. This is done with a hybrid system that combines conventional synchronization at a frequency of 100 MHz and an Ethernet-based White Rabbit temporary system [2], ensuring synchronization with a central clock based on a GPS-disciplined Rubidium Oscillator (GPSDO) with an accuracy of 0.2 ns.

During the winter season of 2017—2018, experiments were performed on 43 optical stations of the first cluster of the TAIGA–HiSCORE system, distributed over an area of 0.4 km^2 on the regular network nodes at distances of 106 m between the stations.

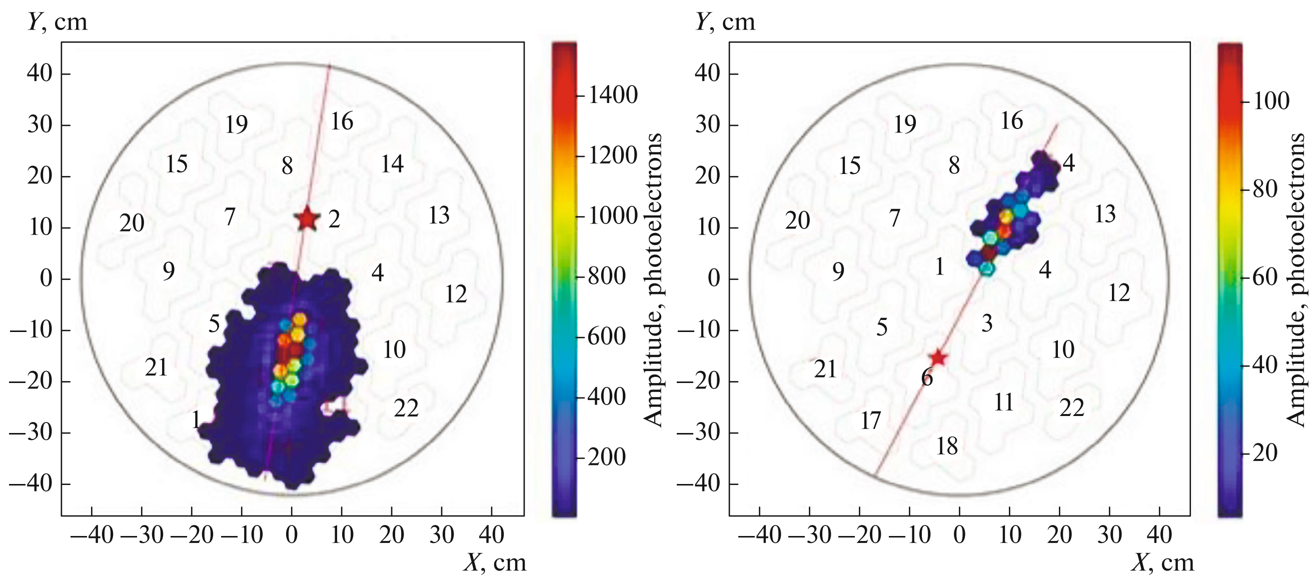

Fig. 2. EAS Cherenkov patterns. Left, hadron-like event: pixel count, 124; size, 18500 photoelectrons; width, 0.38°; alpha, 11.2°. Right, gamma-like event: pixel count, 23; size, 709 photoelectrons; width, 0.18°; alpha, 8.8°. The lines and the asterisk show the direction and position of the EAS axis, reconstructed using TAIGA–HiSCORE data and rescaled to the coordinate system of the telescope's camera.

The EAS parameters are reconstructed from the results obtained with the TAIGA–HiSCORE setup using different techniques and algorithms developed for Tunka-133 data processing [3, 4]. The direction of EAS arrival is found from the relative delay in each station recording a Cherenkov pulse. The primary particle energy is reconstructed from the Cherenkov light flux density (Q200) at a distance of 200 m from the axis with an accuracy of around 15%. The angular resolution is around 0.10° for events with more than 10 activated stations, as was verified by recording the light from a lidar installed on the ISS [5].

THE TAIGA–IACT SYSTEM

TAIGA–IACT telescopes are reflector telescopes with the Davis–Cotton system (Fig. 1a). The total area of each composite mirror is around 10 m^2, the total diameter is 4.32 m, and the focal length is 4.75 m. For protection against frost, all mirrors are blown with hot air. A camera with a viewing angle of 9.72°, in which EAS Cherenkov light is recorded by a PMT matrix, is installed at the focus of the telescope's mirrors. The total camera diameter is around 110 cm. All 560 PMT XP1911 cameras are divided into clusters, each with 4 groups of 7 PMTs (Fig. 1b) with a single divider board and one high-voltage supply source. The groups of a cluster are united by one cross-board with a 64-channel pulse digitizer on top that is based on an ASIC MAROC-3 integral microscheme.

During the winter season of 2017–2018, over ten thousand joint events, including 300 in the opening angle of 0.7° relative to the direction toward the Crab Nebula, were recorded by the TAIGA–HiSCORE and TAIGA–IACT installations. Most of these events produced the Cherenkov images expected for hadron-generated EASes (Fig. 2a), although some were likely due to gamma quanta (Fig. 2b).

CONCLUSIONS

Our immediate goal is to build the first series of the TAIGA gamma observatory with 110–120 broad-angle optical stations in an area of 1 km^2 before the end of 2019, along with three IACTs. The expected integral sensitivity of this complex for registering gamma radiation energy of 100 TeV over 300 h of observing a source is approximately $2 \times 5 \times 10^{-13}$ TeV cm^{-2} s^{-1}, which exceeds the sensitivity of existing or planned installations in these areas of superhigh energies. It is planned to expand the effective area of the TAIGA gamma complex to 10 km^2, the number of TAIGA–HiSCORE optical stations to 1000, and the number of IACTs to 16. Underground muon detectors with a total area of 3000 m^2 will also be deployed.

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