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Studying Ultrahigh-Energy Cosmic Rays with the Tunka Radio Extension

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Abstract—The Tunka Radio Extention (Tunka-Rex) is an array of radio antennas located at the TAIGA (Tunka Advanced Instrument for Cosmic Ray Physics and Gamma Astronomy) facility. The array occupies an area of approximately 3 km^2 and contains 63 antennas. The results from the first two seasons of Tunka-Rex operation (2012–2014) and antenna array modernization (2015–2016) are presented.

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INTRODUCTION

Using antenna systems to detect radio radiation from extensive air showers is a promising technique for cosmic ray research. This method works regardless of the time of day and weather conditions (excluding thunderstorms) and is cost-effective, and the radio antennas are fairly easy to operate. Radio radiation detectors are highly accurate in determining such basic parameters of showers as the energy and the depth of the shower maximum. However, the threshold of radio radiation detection is relatively high, and measurements can be performed only at PCR energies exceeding 10^{17} eV.

Two major mechanisms of the formation of radio radiation from showers are known: the geomagnetic mechanism [1] and the Askaryan mechanism [2]. The first of these makes the main contribution to radio radiation and consists of separating electrons from positrons in the shower front during its propagation in the terrestrial magnetic field. The motion of charges induces current directed perpendicular to the magnetic field and the shower axis. The polarization of this radiation is thus codirectional with the Lorentz force. The Askaryan mechanism originates from an excess of electrons arising due to ionization of atmospheric atoms and positron annihilation. The variation in the excess charge over time produces radially polarized radio radiation. Although the contribution of this mechanism to the resulting radiation is just ~10%, it is substantial and should be considered in processing and interpreting measurement results [3].

The technique of detecting radio radiation from showers was adopted in cosmic ray research immediately after the publication of theoretical works (see the extensive bibliography in [4]). Two units are currently operating in Russia: one at the Yakutsk YaKUSHAL observatory [5] and the Tunka-Rex setup at the Tunka Astrophysical Complex [6].

THE TUNKA RADIO EXTENTION

The Tunka Radio Extension (Tunka-Rex) is a detector of shower radio radiation located at the TAIGA (Tunka Advanced Instrument for Cosmic Ray Physics and Gamma Astronomy) facility [7]. The detector occupies an area of 3 km^2 and contains 63 antennas (25 of which are connected to the Tunka-133 facility [8], and the remaining 38 antennas are connected to the Tunka-Grande facility [9]). The three installations (Tunka-133, Tunka-Grande, and Tunka-Rex) perform simultaneous measurements of showers from primary cosmic rays with energies ranging from 10^{16} to 10^{18} eV. The mutual arrangement of antennas is shown in the figure. Each Tunka-Rex

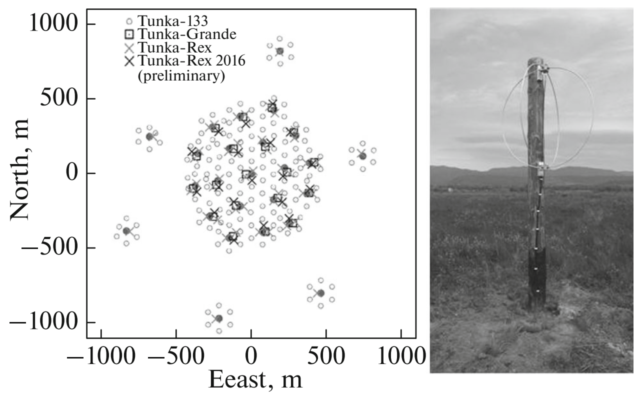

Diagram of the Tunka-133, Tunka-Grande, and Tunka-Rex facilities with provisional coordinates of the new antennas (left) and an external view of an antenna used in Tunka-Rex (right). Tunka-Rex was modernized in the period 2012–2016.

antenna is an active two-axis loop antenna of a special type [10] (see figure), oriented such that loops are directed to the magnetic northwest and northeast. The directivity pattern of such antennas is suppressed in the lower hemisphere, so the antenna gain depends only weakly on the properties of the underlying surface. The antenna pass band (30–80 MHz) is determined using a filter amplifier. The lower boundary is set at 30 MHz, due to the presence of a great many short-wave radio stations and strong natural radio noise (of primarily thunderstorm origin) at frequencies below 20 MHz. The upper boundary corresponds to characteristic wavelengths of coherent shower radio radiation.

Shower observations have been condicted since 2012 by 18 antennas operating jointly with the Tunka-133 facility on clear moonless nights from October through April. The overall number of Tunka-Rex antennas was raised to 44 in 2015 and to 63 in 2016. New antennas were connected to the Tunka-Grande facility. Since 2015, the Tunka-Rex has been operated in combination with the Tunka-Grande facility. This mode of operation allows both day and night measurements. Data regarding the number of antennas and modes of operation in 2012–2016 are presented in the table.

The noise conditions at the Tunka-Rex site are currently unfavorable. Action has been taken to reduce the radio noise and its effect on the measuring equipment; this should help raise detector sensitivity in the future.

DATA PROCESSING TECHNIQUES AND OBTAINED RESULTS

Events detected by at least three antennas with a signal-to-noise power ratio of more than 10 are selected for reconstruction. The plane front model is used to reconstruct the shower axis. If this reconstruction differs from the primary detector (Tunka-133 or Tunka-Grande) by more than 5°, the event is rejected. The primary particle energy and the depth of shower maximum are then reconstructed. The primary particle energy and the depth of shower maximum for selected events are determined using a spatial distribution function (SDF) for amplitudes. This function characterizes the dependence of the signal amplitude on the distance to the shower axis. The primary particle energy is proportional to the SDF value at a distance of 120 m, and the depth of the maximum is proportional to the SDF slope at a distance of 180 m. Comparison of the energy and depth of the maximum values reconstructed at Tunka-133 and Tunka-Rex showed that the error in reconstructing the primary particle energy at Tunka-Rex was 15%, while the error of reconstructing the depth of the shower maximum was 38 g cm^{-2}.

Determining the mass composition of primary cosmic rays became the new goal of the experiment after modernization. A technique for shower axis reconstruction based solely on radio observations must be developed in order to accomplish this goal. In addition, the electromagnetic shower component must be measured jointly by Tunka-Rex and Tunka-Grande. These objectives are currently being addressed.

CONCLUSIONS

In its first two years of operation, Tunka-Rex has proven itself to be an efficient instrument for reconstructing the primary particle energy and depths of the maxima of extensive air showers. Working in combination with the recently commissioned Tunka-Grande terrestrial particle detector, the radio setup

Modernization of Tunka-Rex in 2012–2016

Measurement season	Number of antennas	Trigger
Oct. 2012–Apr. 2013	18	Tunka-133
Sept. 2013–Mar. 2014	25	Tunka-133
Oct. 2014–Apr. 2015	25	Tunka-133
Sept. 2015–June 2016	44	Tunka-133, Tunka-Grande
Oct. 2016 onwards	63	Tunka-133, Tunka-Grande

modernized in 2015–2016 with triple the number of antennas should facilitate the acquisition of statistics on high-energy cosmic rays at the Tunka Astrophysical Complex and allow us to examine their mass composition in detail.

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