Accelerated ions and selfexcited Alfvén waves at the Earth's bow shock

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Abstract. **On the basis of long and continuous registration of the ionization jerks in the thick-wall ionization chamber ASK-1 (with a lead screen of 12 cm Pb) in Yakutsk, we received an energy spectrum of secondary μ-mesons (muons) in the atmosphere at the heights of the first collisions of primary cosmic rays (CRs). The power-law index of the spectrum is equal γ =2.187 $\pm$ 0.065. It is shown that the amplitude of ionization jerks in the chamber is proportional to energy of μ-mesons. The threshold for registration of muons that form ionization jerks is determined to be about 6.5×10^{11} eV. In differential amplitude distribution of ionization jerks a number of peculiar features are revealed. When assuming the jerks are caused by the particles with discrete distribution on masses, the estimate of a cross-section of their interaction with material of the chamber screen of 10^{-41} cm^2 can be obtained. From the corresponding scientific publications, the cross-section of such size is known to be characteristic for the WIMP-particles having the masses about 100 GeV (i.e., about 100 times bigger than the proton mass).**

Keywords: **cosmic rays, ionization jerks, muons**

I. Introduction

In the structure of Yakutsk installation complex for observations of cosmic ray variations there is an automatic cosmic-ray station ASK-1, or ionization chamber of large volume (for ASK-1 description in detail see [1]). This unique device has a lead screen with a width of 12 cm Pb, and its geometric factor is G = 1.17×10^4 cm^2. When a secondary cosmic-ray particle of high-energy (for example, a muon with the energy E $\geq 10^{12}$ eV) interacts with the screen material, this causes a shower of secondary particles that produce a large ionization current in the ASK-1 screen, i.e., ionization sharply increases. Such a current for about 1-2 (or even more) of magnitude exceeds the background chamber records, and the events of this type are usually called "ionization jerks" (IJ). An occurrence rate of these phenomena is rather low. For example, the chamber ASK-1 placed in Yakutsk registers in all about 1-3 jerks per day. The ASK-1 data allow to study in detail some physical properties and possible nature of jerks of various sizes (amplitudes) [2], [3], [4]. In particular, a number of peculiarities in differential distribution of the jerks on their amplitudes seems to open interesting possibilities for the search of unknown, hypothetical particles (e.g., of the WIMP-particles) in the primary cosmic radiation.

II. Ionization Jerks

Besides of total cosmic-ray intensity, the chamber ASK-1 registers the ionization jerks. Jerks represent sharp increases of instantaneous value of the ionization current relative to its average value. On a film of the recording device the jerks are marked by distinct increases. These phenomena are due so-called δ-showers (e.g., [2], [3], [4], [5], [6]) produced by energetic mesons in the chamber screen. The electron-nuclear showers also play a significant role in creation of jerks in the chamber. When studying the usual variations of cosmic rays (e.g., Forbush-effects etc.) the ionization current value created by jerks is subtracted from the total ionization current value.

III. Statistics of Ionization Jerks

For the entire period of observations (above 50 years), the ASK-1 chamber has registered in total 59125 jerks. In early studies [2], [3], [4], where a jerk statistics was rather poor (usually about 1500-2000 cases were undergone to the analysis), different research groups have already noted some peculiarities of the IJs. In particular, it was noted that IJs are rather rare events, with their occurrence rate of 1-2 cases/day per 1 m^2 of the ASK-1 surface [1]. Usually, they were ascribed to the secondary cosmic-ray muons with the energy above 10^{11} eV. Amongst them, there were registered a few of much more rare events ($\sim$1-2 jerks per $\sim$10 days) in the form of very strong jerks that differed radically from the jerks produced by the cosmic-ray muons. Such events were not considered at all, and it was believed that these extremely strong jerks are due to energetic particles from extensive air showers (EAS) or due to some unknown particles that have a high ionization capability [2], [3], [4] (see also [7], [8]).

IV. Some Implications of the ASK-1 Data

On the basis of long and continuous jerk registration in the thick-wall ionization chamber ASK-1 (with a lead screen of 12 cm Pb) in Yakutsk, we received

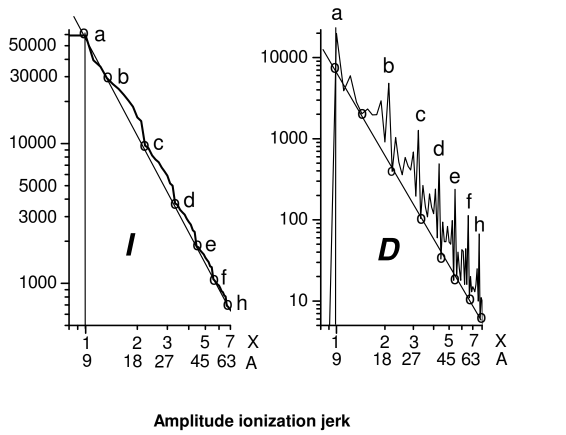

Fig. 1: The integral (I) and differential (D) distributions of the jerks on their amplitudes.

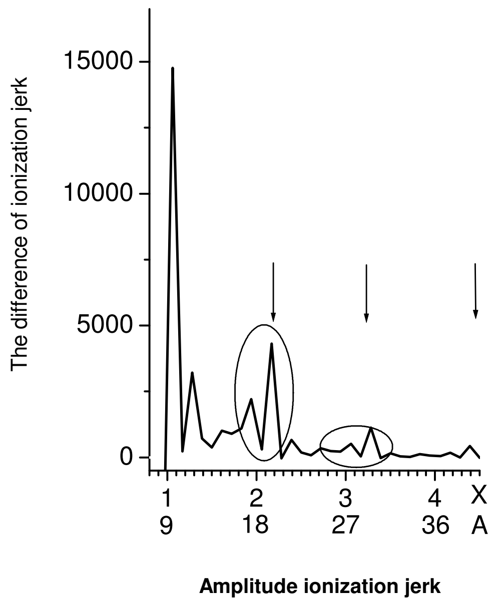

Fig. 2: Differential distribution of the jerk surplus above the cosmic-ray background.

an energy spectrum of secondary μ-mesons (muons) in the atmosphere at the heights of the first collisions of primary cosmic rays. The power-law index of the spectrum is equal $\gamma = 2.187 \pm 0.065$. It was shown that the amplitude of ionization jerk in the chamber is proportional to energy of μ-mesons. The threshold for registration of muons that form ionization jerks is determined to be about 6.5×10^{11} eV. In differential amplitude distribution of ionization jerks a number of peculiar features are revealed. When assuming the jerks are caused by the particles with discrete distribution on masses, the estimate of 10^{-41} cm^2 for a cross-section of their interaction with material of the chamber screen can be obtained. From the corresponding scientific publications, the cross-section of such value is known to be characteristic for the WIMP-particles (e.g., [8]) having the masses about 100 GeV (i.e., about 100 times bigger than the proton mass).

Based on the total set of the ASK-1 data (59125 records) we constructed the integral (I) and differential (D) distributions of the jerks on their amplitudes (Figure 1). The figure shows absolute jerk amplitude A in the units of device counts and their relative amplitudes $X = A/A_0$, where A_0 is a threshold (background)) amplitude value. By circles are marked the positions of specific points in the distributions, namely, of the minimum values in additional jerk count surplus relative to that from cosmic-ray background. One can see that the CR jerk background itself is monotonous and reveals almost strict power-law dependence on the jerk amplitudes.

sectionDifferential distribution of the jerk surplus above the cosmic-ray background

Figure 2 shows differential distribution of the jerk surplus above the cosmic-ray background. It is assumed that a spectrum of the background jerks is monotonous and, in practice, has a power-law form, because the primary CR spectrum has a monotonous character. On the other hand, in the IJ distribution there are seen two types of peculiarities (marked in the figure by ellipses) that differ significantly one from another, at least, in two respects.

The first distinction is related to the jerk sequence in the pulse. Namely, in the cases of very rare, but large events (peculiarities of the (b), (c), (d) ... type, marked by ellipses and arrows) we see firstly a small peak, and then a large one, and this feature repeats most frequently. In the case of the peculiarity of the (a) type, at small jerk amplitudes (at small X values) the situation is opposite: a large peak appears first, and then we can see a small one.

The second distinction concerns the change of the peak magnitude along the horizontal axis. In this respect, the peculiarities of the (b)-(h) types differ in size very significantly, and there are no other bursts between them.

V. Nuclear component of primary cosmic rays and jerk generation

As follows from our analysis, the first (largest) peak in the amplitude distribution of the jerks (the left side of Figure 3, peculiarity of the (a) type) may be explained by jerk generation due to secondary μ-mesons from primary cosmic-ray protons. The second (smaller) peak covers rather narrow range of X values. Nevertheless, its appearance shows that the chamber ASK-1 is able to single out the primary cosmic-ray flux not only protons, but also some other particles (probably Z-component) with a certain Z value [7].

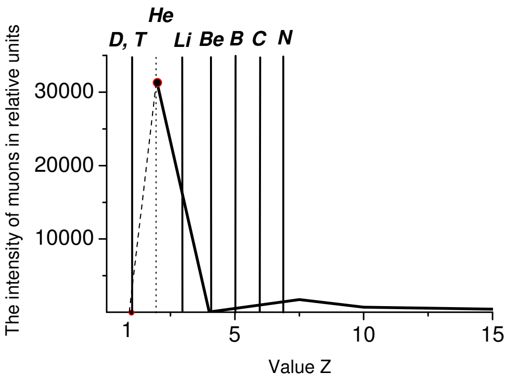

Fig. 3: Distribution of μ-muons versus Z value.

VI. MAIN CONCLUSIONS

1. The power-law index of the jerk number spectrum in the ASK-1 chamber on their amplitudes is equal to average index of energy spectrum for secondary muons $\gamma = 2.187 \pm 0.065$, and the amplitude of IJ in the chamber is proportional to energy of μ-mesons near the Earth's surface. The threshold energy for registration of muons that form ionization jerks is determined to be about 4.82×10^{11} eV. These estimates are in a good agreement with the results of early studies.

2. In the differential IJ distribution we have found a number of peculiarities (peaks) that require non-trivial interpretation. General picture of the IJ distribution on their amplitudes, with radical distinctions in the peak forms, are probably conditioned by two kinds of particles. The first kind of peculiarity is due to cosmic rays, more exactly, due to secondary muons with the energy above 10^{11} eV from the primary protons and heavier nuclei (two first peaks in the range of relatively small jerk amplitudes). The peculiarities of second type seem to be caused by the particles of unknown origin (all the rest peaks in the range of large amplitudes where a number of events is considerably smaller).

3. Analysis of the rare, but powerful ionization events in the ASK-1 chamber seems to open interesting possibilities for the study of the properties of known cosmic-ray particles with a large charge at high energies and for the search of unknown particles (e.g., of the hypothetical WIMP-particles [8]) in the primary cosmic radiation.

VII. ACKNOWLEDGMENTS

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