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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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THE PERSPECTIVE FUNDAMENTAL COSMIC RAYS PHYSICS AND ASTROPHYSICS INVESTIGATIONS IN THE TIEN SHAN HIGH-MOUNTAIN SCIENTIFIC STATION

Abstract. In this paper, we have presented research results achieved in the areas of cosmic rays physics and astrophysics in the Tien Shan high-mountain scientific station. The research was conducted by Physicotechnical Institute in cooperation with other teams. According to the research program, the fundamental subject area comprised the following sections: investigating new processes in the cosmic rays (CR) at energies above 10^{17}eV on the "Horizon-T" installation; a comprehensive study of the extended air showers (EAS) properties on the shower installation in the range of the (CR) initial spectrum breaking (10^{14} – 10^{17} eV); search of structures in the particles distributions from EAS forward cone at high energies on the "Hadron - 55" installation; earch and investigation of the cosmic rays gamma sources with energies above 0.5 TeV on the "Hadron-55" installation; registration and investigation of the radio emission from EAS; investigation of the Earth's crust tension degree of the Almaty seismically active region by registering high energy cosmic rays muons.

Key words: cosmic rays, spectra, kink of the primary spectrum, stormwater installation, wide air showers, radio emission, thunderstorm phenomena, degree of earth crust intensity, seismically active region, muon interaction.

Introduction. The researchers of Physico-technical Institute study cosmic rays (CR) since the end of the 1950's. The institute has highly qualified researchers, unique Tien Shan and Intermediate scientific stations located at 3340 m and 1700 m above the sea level. Modern level of the conducted investigations and high quality of the results derived by the Tien Shan high-mountain scientific station were stipulated by many years of wide and comprehensive cooperation with the leading Russian Research Institutes, namely with Physical Institutes after Lebedev of the Russian Academy of Sciences and by active involvement in the International scientific projects. Collaboration that exists between Physical Institute after Lebedev of the Russian Academy of Sciences and Tien Shan high-mountain scientific station is realized by virtue of the program of joint investigations between research institutes and universities of Kazakhstan and Russia, as well as the Consortium Agreement on establishing "Eurasian high-mountain scientific Centre of the cosmic rays". Later, Kazakh National University after al Farabi and Ionosphere Institute joined this agreement.

For tackling more fundamental and applied problems using the station located at 3340 m above sea level, research teams of the above-mentioned institutes implement research investigations on the following topics:

– a comprehensive study of the extended air showers properties (EAS) on the shower installation in the range of the (CR) initial spectrum breaking (10^{14} - 10^{17} eV);

– searching of structures in the particles distributions from EAS forward cone at high energies on the "Hadron - 55" installation;

– searching and investigation of the cosmic rays gamma sources with energies above 0.5 TeV;

– registration and investigation of the radio emission from EAS;

– investigation of the Earth's crust tension degree of the Almaty seismically active region by registering high energy cosmic rays muons;

– studying thundery phenomena as well as neutrons and muons at the depth of 10 meters of the rocky ground.

In what follows, we provide a more detailed discussion of some of the afove-mentioned.

Results and Discussion.

A compex study of EAS properties in the range of cosmic rays primary spectrum fracture (10^{14}–10^{17} eV) on the shower installation. As a result of many years investigations and at the present stage of science development, a general form of the galactic cosmic rays (CR) energy spectrum became known. According to these results, the cosmic particles flux registered to the present time varies in an extremely wide range of the initial energy E_0 values: the range scale makes up no less than 10 orders of magnitude. The respective intensity of their differential energy spectrum falls by 28 orders of magnitude of the value at the transition from low energy particles to the known highest values of E_0. Throughout the whole of range the spectrum has a universal power-series shape, while its γ index varies sharply at some characteristic points: in the energy range $E_0 \sim 3{\cdot}10^{15}$ eV, where the well-known primary spectrum "fracture" is found [1-7], in the region of the slightly visible “second fracture” with $E_0 \sim 2{\cdot}10^{17}$ eV [8], at "anti-fracture" $E_0 \sim 3{\cdot}10^{18}$ eV [9], and in the "cutting" region $E_0 \sim 5{\cdot}10^{19}$ eV [10,11].

The heterogeneities in a single power spectrum of the CR can occur as a result of influence of utterly different factors such as loss of efficiency of the galaxy sources for particles acceleration with their energy growth; prevalence of the CR extragalactic component in the very high energy region; effects of CR propagation in the interstellar medium; local peculiarities of the spatial region surrounding the Solar System; occurrence of some abnormal component with unusual properties of interaction in the natural flow of cosmic particles with unusual properties of interaction with normal matter.

For making a final decision among the aforementioned hypotheses, we need an utmost detailed information about behavior of primary spectrum in the energy range between 10^{15} and 10^{18} eV. This stipulates a necessity to implement detailed CR flow measurements in this field with rich statistical data. For such measurements, 80 scintillation detectors are built and used on the station in the launch building and outside of it, as well as system of electronic registration was designed ensuring in this energy range are created and used currently (figures 1 and 2). Due to further increase in detectors’ area, it is expected that the possible numbers of particles interaction with energy above $3{\cdot}10^{15}$ eV will reach more than 4500 events per year.

The structures searching in particles distributions from the forward cone of the extended air showers (EAS) at high energies on the “Hadron-55” installation. Deeper understanding of multiple processes in the narrow forward cone of EAS represents one of the most significant problems of CR physics. Recent international studies of EAS trunks on the Tien Shan and Pamir-Chakaltai stations as well as the stratospheric experiments have shown new results [12]. In the context of this problem, the following two unique phenomena that were discovered should be noted:

– events with anomalous relation of charged and neutral components, so-called *centaur* of the event; and

– phenomenon of coplanar particles emission, the events with the geometrical alignment.

Critical and detailed review of relevant problems in nuclear interactions on the «Quark Matter 2017» conference revealed quite new, ambitious and valuable results [13]. The advanced correlated approaches are effective tools for studying initial stages [14] and dynamic evolution of multiple processes [15]. The investigation of the particles of two-hadron correlations in *p-p*, *p-A* and *A-A* interactions in BNL on RHIC and on LHC in CMS, ATLAS, ALICE revealed the extremely important distant correlations – “ridges”, several units of length by rapid distributions, concentrated on two azimuths: “near-side” and “away-side”

Figure 1 – Scintillation detectors installed in the launch building

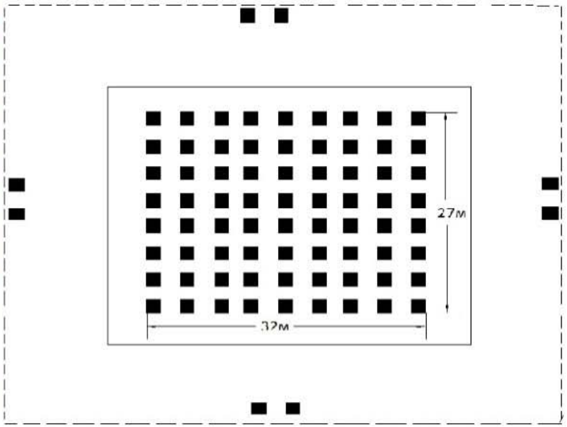

Figure 2 – Layout chart of scintillation detectors in the launch building and outside

[16, 17]. In the forward cone the рапидитириджи were detected in the recent LHCb-experiment [18]. It should be noted that such correlations, called «alignment», were revealed for the first time during the experiments with X-Ray films (1998), exhibited in the Pamir mountains [19].

An interesting opinion about complanarity in cosmic rays was presented [20] in comparison with large hadron collider (LHC) results. For studying and investigating possible centaur type events, new detector CASTOR (Centauro And Strange Object Research) was designed and implemented, as part of the LHC CMS experiment [21]. Both LHC [22] and RHIC [23] developed and suggested new ambitious research of multiple generation processes in the EAS narrow forward cone. Our research team carried out an analysis of multiple generation processes both in CR at high energies and at the accelerating energies [24]. In the protons and the CR light nuclei generated multiple processes in the TeV regions, a well-defined dependence of multiple generation processes from interaction region dimensions was revealed [25].

It is very important to compare the experimental data received by cosmic rays on "Hadron-55" complete installation with the large hadron collider experiments [26]. In figure 4, the results of double-particle angular correlations for the charged particles arising in the proton-proton collisions at the 7 TeV center-of-mass energy by wide range of pseudorapidity (η) and azimuth angle (φ) received on CMS detectors are shown [27].

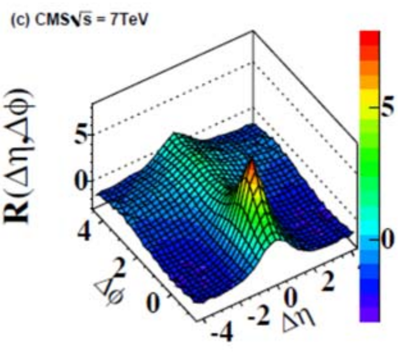

Figure 3 – Distribution of the two-dimensional correlation function for events with large multiplicity from the experiment in P-P interaction at 7TeV energy in LHC [27]

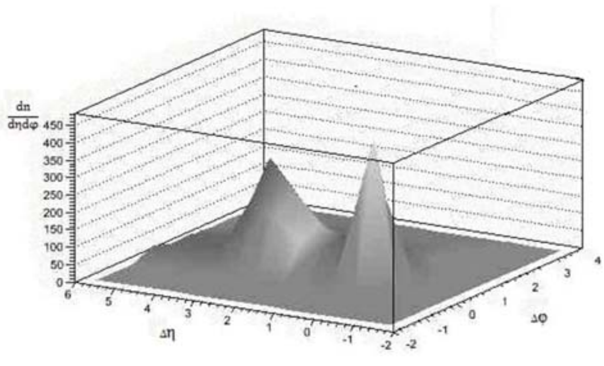

Figure 4 – Distribution of the two-dimensional correlation function for events with large multiplicity by the "Hadron-55" data [26]

In figure 5, double-particle angular correlations distribution for particles received as a result of interaction of the cosmic rays particles for events with large multiplicity, arising in the “Hadron-44” installations dense target, located at a height of 3340 meters above sea level at energies near to the CMS [26]. As can be seen from figures 3 and 4, a certain similarity between them can easily be established.

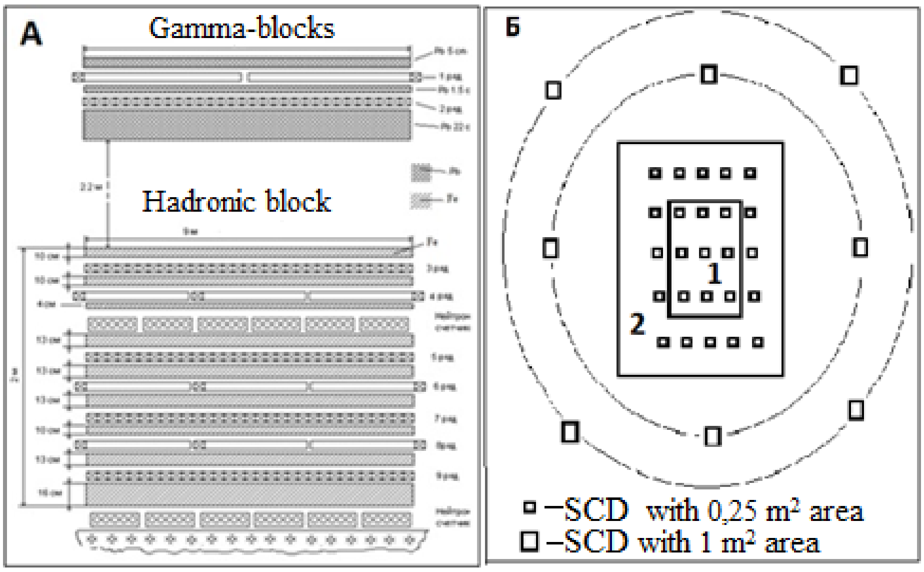

Figure 5 – A – ionization calorimeter, composed of gamma-blocks and lower on 2,2 m hadronic block.
B –installation detectors disposition circuit (top view): 1 – calorimeter disposition in the laboratory housing;
2 – SCD by 0,25 m^2 area disposition in the laboratory housing. In the closest circle within a radius of 40 m and in large circle within a radius of 100 m in fours SCD with 1 m^2 area are disposed

The upgraded complete installation "Hadron-55" is located in the building and outside. In the building with 324 m^2 area and its height of more than 10 m, there are ionization calorimeter by 55 m^2 area and 1050 g/cm^2 of thickness, as well as 25 scintillation detectors (SCD). Outside the building by the imaginary circles with radii of 40 and 100 m are located four SCD (with 1 m^2 areas) for the primary particle moving trajectory determination. The ionization calorimeter circuit and SCD disposition are presented in the figure 5. The installation construction allows determine energies of the electron-photon, hadronic and neutron components of the cosmic radiation, as well as recover particles trajectories. In consideration of calorimeter and neighbouring infrastructure areas (32400 m^2), which will considerably increase further on, one can estimate that the interaction numbers with energies above $3{\cdot}10^{15}$ eV will make up more than 5000 events per annum. The peculiarity of the "Hadron-55" installation consists in the fact that it represents the complex of various detectors that permits to investigate the cosmic radiation particles interaction characteristics in more detail.

Nowadays, in high-energy physics there are several sufficiently different among themselves phenomenological models of the hadronic interactions that are used, each of which claim adequate description of the hadron-nucleus interaction at the extra-high energy. Their difference leads to considerably different conclusions about the nature of coplanar generation of the most energetic particles as part of the extensive air shower (EAS). The latter cannot be described by the hadronic interactions conventional models - events of "centaur" or "anti-centaur" types with abnormally high part of energy released to the charged component or, on the contrary, to the neutral component. Abnormally weakly absorbing hadrons observation enabled us to question the cosmic rays (CR) long-range nuclear-interacting component in the region of the spectra breaking in the mass composition of the primary cosmic rays (PCR). The latter were resulted from inverse problem solution – the spectra parameters and PCR composition recovery by EAS observed characteristics.

Since the problem of primary cosmic rays composition at the super high energies is far from being solved, the initial set of goals that hold for EAS complete installations are as relevant as before. Today, however, this problem can be solved in a more effective way by applying more advanced understanding of this problem and using progress of the last two decades in the field of experimental and computer technologies, thereby permitting to use new methods of experimental data processing and analysis. This very approach was used as a foundation in the "Hadron-55" project, which according to us is capable to make progress in terms of solving classical problems (the primary cosmic rays parameters investigation and building interaction model) that are relevant within the context of EAS complex installations.

Searching and investigating cosmic radiation gamma sources with energy above 0,5 TeV. Today, almost all experiments in the area of cosmic rays are accompanied with design or development of the installations for investigation in the field of gamma-astronomy. This happens because explosive processes of generation and acceleration of protons and nuclei are accompanied by generation of gamma-quanta and neutrino, which are flying along straight line in the magnetic field of the Universe without scattering. That, in turn, makes possible to investigate catastrophic by energy release interactions in the Universe and define their place. Moreover, different models and theories of development of the Universe are created and verified on the base of the experimental data received in the gamma-astronomy field. All that makes important development of the gamma-astronomy experimental investigations and methods of their observation.

At the «Energetic Cosmos Laboratory – New Opportunities» workshop, which was held on the September 13, 2016 and the «Exploring the Energetic Universe 2017» International scientific Conference (7-12 August 2017) organized by Nazarbayev University (The laboratory of the Nobel Prize Laureate D. Smuth), a decision was made to extend gamma-astronomy investigations [28], in which the "Hadron-55" complete installation can be used (figure 5).

Studying gamma-quanta with energies above 0.5 TeV by using gamma-ray telescopes installed on spacecrafts is practically impossible due to smidgen of such high-energy particles flows, and small aperture of telescopes, which can be put onto the Earth orbit. Therefore, the ground installations are the basic instruments for the gamma-quanta origins investigation. Thanks to Cherenkov optical telescope discovery and launched Fermi-LAT [28] satellite, today thousands sources of gamma radiation are known. Optical gamma-telescopes mostly operate in the range of 10 GeV – 10 TeV energies and register Cherenkov light generated by wide air shower.

One of the modern telescopes HESS (The High Energy Stereoscopic System) [30] is located in Namibia and consists of 4 parabolic plates, 12 meters in diameter. On top of each of them there are 382 circle mirrors which register the Cherenkov radiation. The fundamental achievement of the HESS telescope at cosmic gamma-radiation registration is that the assumption that supernova remnants are the cosmic rays sources has been validated.

In our work for performing investigations in high-energy gamma-astronomy region, we use a modernized ionization calorimeter with scintillation detectors field with area of 31 400 m^2. The ionization calorimeter consists of two parts: upper gamma-block and bottom hadronic-block, which are divided by two-meter spacing (figure 5). The gamma-block registers by virtue of absorption the electron-photon components (EPC) of cosmic rays. The hadronic component is passed through gamma-block without interaction as a result of gamma-block small thickness and begin to interact and generate particles in the hadronic-block. The project’s scientific novelty consists in implementation of gamma-astronomy investigations using an air shower method, that is without the expensive Cherenkov detectors. The idea of the project is to select events with interaction in gamma-block only and with no interaction in the hadronic block, that is pure EPC are selected. In order to make a dependable measurement of the primary particles trajectory, the scintillation detectors network are used, which are provided by equipment with resolution up to nanosenconds. The present installation have the following advantages in comparison with standard registration of the Cherenkov radiation from the atmosphere:

1. If observation period of Cherenkov radiation from atmosphere is limited by night, moonless and cloudless periods (5-10% from calendar year), then observation period of complete installation reaches nearly the calendar year.
2. In the gamma block of the installation we receive the EPC energy and geometric distributions while studying the same gamma-source with accuracy within the ionization chamber width. Transferable scintillation detectors have square from 0.25 to 1 m^2. Disposition of these detectors on the station area is shown in figure 5.
3. Angle of the simultaneous view of the scintillation installation is large and with Earth rotation in one of the experiments, the region of the celestial sphere of several steradians is visible. Enormous amount of information can be regulated using electronic methods by changing registration threshold. With availability of large memory capacity, we can register all interactions and, further on, by using a program we can select and investigate right events.

The following questions can be attributed to the project scientific problems:

– statistic simulation of air showers for gamma-astronomy experiments;

– obtaining energy distributions of galactic and extragalactic pinpoint gamma-sources;

– studying diffuse gamma-sources (galactic halo, Fermi bubbles, dark matter decay);

– collective registration of air showers by several installations of the station.

As a review of the previous research implemented in our area of the project, it is necessary to note the following. The main competitor of air Cherenkov telescopes in the field of high-energy gamma-quanta detection are shower installations. In these installations, a shower of the secondary charged particles is registered and its energy is determined. However, extraction of showers originated from gamma-quanta above the hadronic showers background happens by virtue of penetrating component and spatial distribution. Nowadays, 48 000 events with energy above 0.5 10^{12} eV are registered by "Hadron-55" installation. The number of hadronless events is about 3360 or 7%. Currently, mathematical programs for events registration, processing and analysis are developed taking into account constructive peculiarities of the installation. Preliminary results of the some processed events are depicted in table 1.

Table 1 – Preliminary results of registration data processing

No.	Energy, 10^{15} eV	Angles, in degrees		Right ascension	Declination	Galactic		Constellation
		Zenith	Azimuth			Latitude	Longitude	
1	2.17	23.7	333.4	4h 29m 59s	62°48′56″	9.8°	145.2°	Camelopardalis
2	0.56	53.2	167.0	2h 39m 04s	-9°01′56″	-58.8°	182.6°	Cetus
3	1.93	37.7	101.3	0h 37m 28s	27°05′33″	-35.6°	119.1°	Andromeda
4	2.72	15.6	206.6	3h 08m 58s	29°02′56″	-18.0°	165.1°	Taurus
5	3.95	27.2	113.2	1h 34m 31s	28°36′55″	-33.3°	134.3°	Triangle
6	1.96	43.2	344.7	8h 05m 16s	78°39′35″	30.1°	135.4°	Camelopardalis

There are no currently own experimental installations in Kazakhstan for implementing research in the field of gamma-astronomy. The proposed project allows conduct investigations in gamma-astronomy field sufficiently fast with new possibilities and small cost.

Investigation of Earth's crust tension degree of Almaty active region by registering cosmic rays muons of high energy. Radiation acoustics is a scientific multidisciplinary area, which is developing between acoustics, nuclear physics and high energy physics. Its foundation is formed by studies and application of radiation-acoustic effects that are nascent at the penetrating radiation interaction with a matter. At the turn of the 80's and 90's of the last century, scientists of the Physical Institute after P.N. Lebedev and Earth Physics Institute (Russia) had developed a concept of a new promising area of seismology: using a signal from elastic vibrations in the acoustic frequency band for earthquake forecasting. These elastic vibrations are generated under local ionization influence, which is formed at the moment when passing of cosmic radiation penetrating particles happens. These particles are high-energy muons and neutrinos, which pass through seismically tense environment in the deeper layers of Earth [30, 31]. The basic idea of this method is illustrated by figure 6.

Earth crust sounding by a beam of penetrating energetic muons and neutrino enables us to conduct direct monitoring of the lithosphere internal state at the depth of 1-10 km that is the closest to the zone of earthquake sources formation. Together with acoustic monitoring of deep environment response on muon beam trigger action, such sounding represents a unique method of direct penetration in the earthquake zone vicinity. Every individual measuring at the muon monitoring is local and all measurements together allow us control considerable volume of the earthquake zone. The size of the zone depends from the sound receiving devices sensitivity, acoustic noise level and installation square for muon flow detection sensitivity.

Studying and analyzing time characteristics of high-frequency seismic noise is one of the directions of developing effective methods for earthquake forecast. One of the possible methods for predicting earthquakes is the method of recording the intensity of neutron and charged particle fluxes, which is based on scintillation and semiconductor detectors [32-37]. In [38], the authors have offered a technique of such

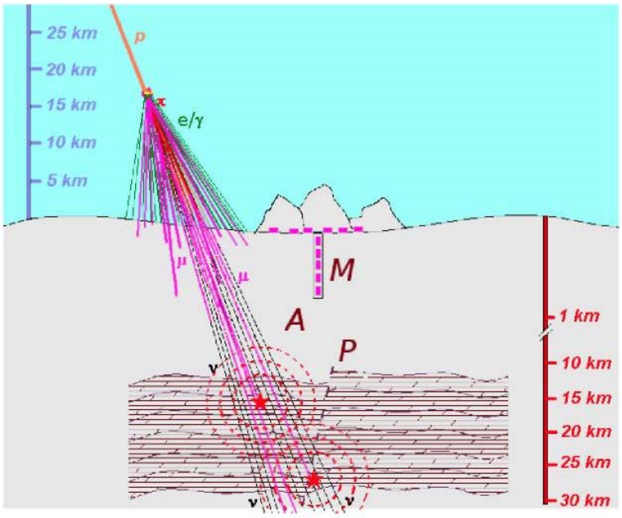

Figure 6 – Model of deeper seismic sounding of Earth's crust on the basis of muons from the energetic EAS trunk:
P is a deep fault zone; A is elastic vibrations are generated in the seismic stretch environment under local ionization influence from muons passing and propagated as acoustic wave; M is a sensible microphones system

forecast, which is based on the concept that earthquake preparation processes cause abnormal behavior over time during intense acoustic noise. The role of a trigger provoking the generation of elastic oscillations in the acoustic frequency range, can cause increase in short-time ionization degree as result of passing of high-energy cosmic rays muons through seismically tense regions of lithosphere. Subsequently this method was quantitatively explained in [39]. In it, authors have studied passing of muons with energy of ~10÷100 TeV through ground using numerical simulation. As a result of this investigation, the authors have determined precise valuations of multiplicity of such muons in EAS with 10^{15} – 10^{17} eV, depth of their penetration inside the Earth crust and number of interactions (microcracks) which such muons can cause inside seismically strained crust region depending on muons' energy and stored energy of elastic deformation. It was also determined that in a significant number of cases formation of such microcracks can generate acoustic waves in the frequency range of 1–2 kHz and with the amplitude sufficient for their registration by sensible microphones located near the surface of Earth.

As emerging of penetrating particles is related to EAS developing in atmosphere, for the purposes of releasing acoustic emission on the noise background described in [40], it is proposed to use the correlation search between acoustic signals and signals on passing of EAS or muonic detector signals (with account of EAS trajectory). This will enable us to implement a direct monitoring of lithosphere internal state at the depths of 1÷10 km. Together with seismic acoustic monitoring of response of deep environment on the muon beam trigger action, this sounding represents a unique method of direct penetration into the comparatively near focal zone vicinity, as compared with other methods. Every individual measurement at the mu-meson monitoring is local, and collectively all measurements implemented at the certain time period enable us to control a certain amount of focal zone. The value of this parameter depends on sensitivity of the acoustic receivers, acoustic noise level and area of installation for detecting mu-meson flow. Searching of acoustic emission short-time signals in the events that are connected with high energy mu-mesons group passage was realized during a special experiment on the Tien Shan high-mountain station in 2012 year. During this experiment, in certain cases acoustic pulses of the significant amplitude in the narrow temporal vicinity (~10 s) were observed after multiple mu-meson events registration.

Nowadays, the Tien Shan shower installation modification is completed and it started EAS regular registration. The well was cleaned out up to 52 m deep, in which a microphone with sensitivity of 20 mV/Pa in the 500 – 10 000 Hz acoustic frequency range was mounted. The preliminary results, which were obtained by implementing such type of measurements, are illustrated in Fig.8. In it, we show examples of events in which distinctive short-time increases in amplitude of both the initial microphone signal and its low-frequency envelope jointly with shower installation data. The latter represent spatial distributions of the charged particles flow density (generally, electrons) for the several EAS, the passing moment of which preceded the acoustic signal moment by < 100 s. The mu-mesons from these EAS trunks in these cases could play the triggering role, thereby invoking generation of elastic vibrations in the depth of Earth crust. On the basis of distributions of particles flow density we can obtain a series of estimations for fundamental shower parameters of EAS data, particularly for shower size (the total number of the shower generating charged particles). For the cases that are shown in figure 7, the size estimations fall in the particles range of 10^5 – 10^7 that corresponds to the initial energy of cosmic rays $\geq 3 \cdot 10^{14}$ eV and multiplicity per one energetic mu-mesons shower of 1÷10 orders of magnitude. Thus, we have determined energy threshold of the acoustic signal response during EAS passing.

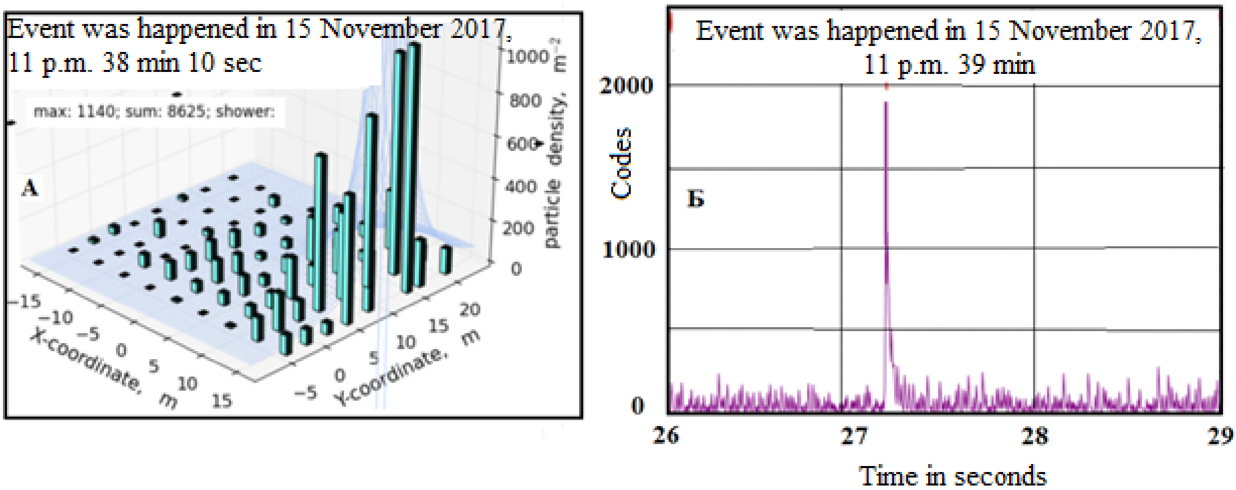

Figure 7 – Short-time events with significant increase in acoustic signal amplitude and EAS particles flow density distribution: A – EAS registration of the shower installation; B – a signal from the seismic event in the records of acoustic detector data

An example of registering acoustic signals and temperature in the well during the earthquake on 30 December 2017. In accordance with RGP IGI Center information, on 30th of December 2017 at 21 hours 55 minutes 43 seconds by Astana time (at 15 hours 55 minutes 43 seconds by Greenwich time) on the 19th km to the south from Almaty, a weak earthquake happened. The focus coordinates are 43.05 degrees of the northern latitude and 76.87 degrees of the eastern longitude. The magnitude was mb=3.3 and energy class – K=7.2. The earthquake source was situated at the depth of 10 km *(www.kndc.kz).* Figure 8 shows the earthquake's epicentrum location relative to the well on the TSHVNS territory as well as on the territory of the Orbita Radiopolygon, where the measuring equipment was installed. Between November and beginning of December 2017, the following measuring equipment was installed in the well: microphone (with sensitivity of 25 Pa/Mv) for acoustic signals registration at the depth of up to 54 m, and three temperature sensors at the depths of 1 m, 24 m and 39 m [41]. There was a hardware and software

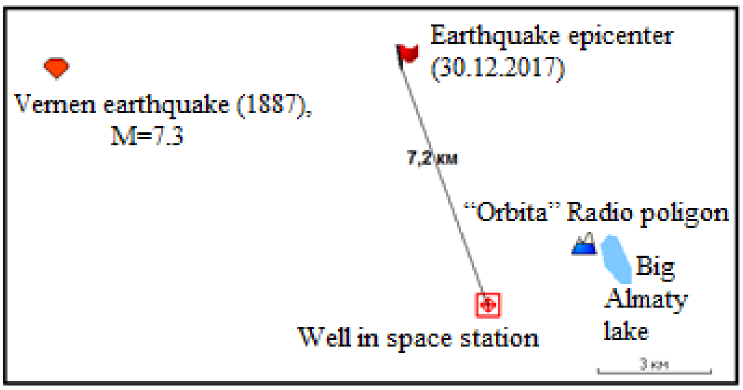

Figure 8 – Locations of earthquake epicenter (30.12.2017) of the catastrophic Vernen earthquake (1887), "Orbita" Radio poligon, the well on the TSHVNS and the Big Almaty Lake

package for infrasonic measurements, which belongs to the Institute of Ionosphere, on the Orbita Radiopolygon. In this institute starting from 2011, a continuous monitoring of infrasonic signals variations in surface atmosphere is traditionally implemented. It can be seen from figure 9 that 30th of December earthquake happened near the operating measuring complex. This gave us a unique chance to use a highly sensitive equipment for registering responses in the acoustic pulses and temperature variations during the earthquake. Registration and analysis of the findings were performed from 1st December 2017 to 10th January 2018.

Figure 9 shows simultaneous recording of the acoustic pulses and temperature variations in the well. The microphone registered two acoustic breaks with maximum the day before of earthquake (23 December) and 30-31 December (during and after, respectively). As can be seen from figure 9a, these breaks occur at the same time with small increase in temperature in the well (Fig. 9b). As mentioned above, the pecu-liarity of the obtained data is that the earthquake's focus and epicentrum was quite close to the well – only 5.3÷7.2 km away. According to the Dobrovolsky's formula [42], the deformation processes in the lithosphere at the earthquake preparation are observed within the range of nominal radius from the epicenter: $R = 10^{0,43M}$, where R is radius in km and M is the earthquake's magnitude.

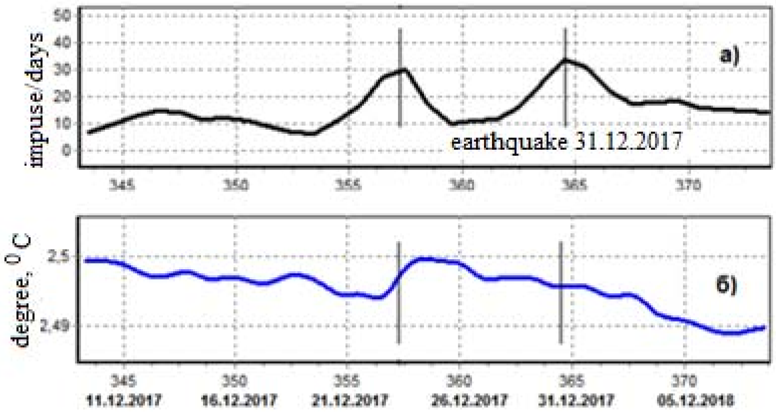

Figure 9 – Comparing acoustic breaks (a) and temperature (b) variations data records registered in the wall a day before, during and after the 30.12.2017 earthquake. By vertical lines we designate the breaks days before and during the earthquake

The Dobrovolsky's formula tells us that for the earthquake with magnitude M = 3.3 (30 December 2017), the radius, within the range of which the deformation processes in the lithosphere take place, equals to 26.2 km. Therefore, location of the downhole measuring equipment location at the distance of 5.3÷7.2 km from the earthquake epicenter fits into the nominal radius and is situated in the zone of the most active processes of the earthquake preparation. This very fact of close location of the well from the earthquake's epicenter allows us register anomalous effects in geophysical fields at the weak earthquake's preparation.

In order to confirm authenticity of the findings, we have performed a concretization of the earthquake's (happened on 30.12.2017) coordinates relative to the measuring well, since the seismological data presented by different seismological services ambiguously determined the earthquake epicenter and the center of origin. Dispersion of earthquake's coordinates according to data of different seismological services, Internet sites, urgent reports, interactive bulletins and prompt catalogues is presented in table 2 and figure 10. As can be seen from table 2 that geographical coordinates of the earthquake's epicenter are different for more than 0.3 degrees (> 30 km) and the earthquake's hypocenter was determined as 3÷10 km. In table 2 we also provide different times of the earthquake's main shock and its magnitude. Therefore, a question arises about the location of earthquake's real epicenter and hypocenter. Does the location of measuring well fit in the circle which is defined by Dobrovolsky nominal radius R? Is the measuring well really situated in the near-field zone (5.3÷7.2 km) or in the far-field zone of the Dobrovolsky's nominal radius?

In figure 10, we depicted earthquake coordinates dispersion by data from different sources.

Thus, we have six different epicenter coordinates of the same earthquake. Among them, some coordinates were situated in the near-field zone, the rest were situated in far-field zone of the Dobrovolsky's nominal radius. To answer a question which seismological service delivered the most precise

Table 2 – Seismological data of different seismological services

Source of data	Latitude NL	Longitude EL	Earthquake time	Depth km	Magnitude	
					Mb	Mpv
НяЦ-1 kndc.kz – prompt catalogues service	43,0515	76,8774	15:55:45,61	0	3,4	3,1
НяЦ-2 kndc.kz – interactive bulletin	43,3584	76,8681	15:55:45,0	3	3,5	3,3
СОМЭ-1 – some.kz prompt catalogues service	43,0900	76,8800	15:55:45	10	–	4,2
СОМЭ-2 – some.kz prompt catalogues	43,1000	76,9000	15:55:45,8	10	–	4,2
RAN geophysical service – ceme.gsras.ru prompt catalogues service	43,23	76,85	15:55:45	10	4,1	
– emsc-csem.org European Mediterranean seismological Centre	43,21	76,76	15:55:45,1	2	3,8	

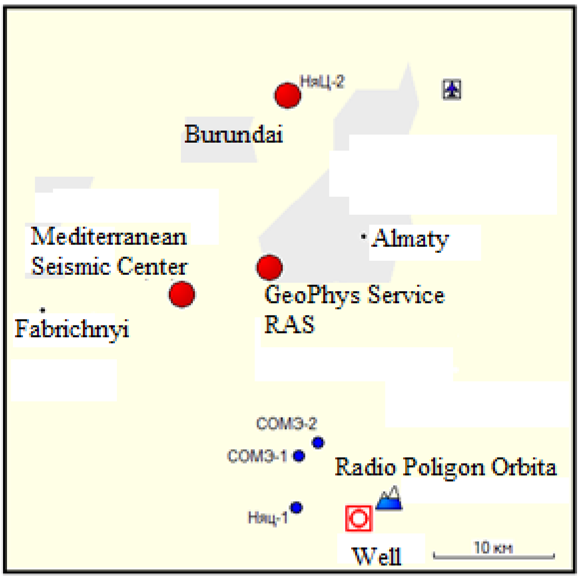

Figure 10 –
The earthquake's epicenter (30.12.2017)
disposition by the data of different seismological services, urgent reports, interactive bulletins and prompt catalogues data relative to the measuring well and the Orbita Radio polygon.
By large circles the epicenters in far-field zone of the Dobrovolsky's nominal radius were labeled; by small circles the epicenters in the near-field zone were labeled

location of the earthquake's epicenter and hypocenter relative to measuring well, we used data of hardware and software package for infrasound measurement, which belongs to the Institute of Ionosphere, on the Orbita Radiopolygon. This infrasonic complex registered appearance of the "surface-atmosphere" (ground-coupledairwaves) exchange waves, which were generated at the expense of the Earth surface vertical displacement at seismic waves transmission through 2.1 seconds after earthquake (figure 11).

It should be noted that the exchange waves were first discovered using infrasonic sensors as early as in the sixties of the last century [43-45]. Taking into account that the seismic wave reached Orbita Radiopolygon from earthquake focus after 2.1 seconds with the speed of 6 km/s, then the calculated distance from the earthquake focus to the infrasonic sensor equals to 12.5 km. With an account of the

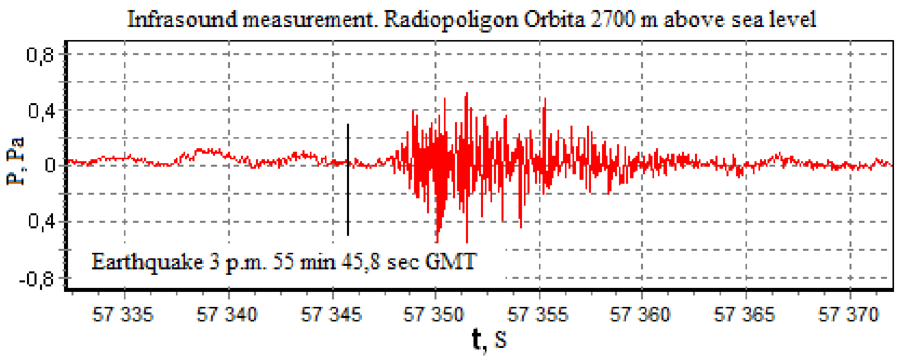

Figure 11 – Using infrasonic sensor to register exchange waves which were generated by seismic wave transmission. Vertical line we mark earthquake's time happened on 30.12.2017

infrasonic measurements data analysis, one can conclude that the best coincidence corresponds to the point with coordinates presented by the some.kz prompt catalogues. Therefore, the well with the measuring equipment was situated in the near-field zone of the Dobrovolsky's nominal radius. Hence one can definitely come to the following conclusions:

– For the seismic processes activation monitoring the new complex of the measuring equipment was implemented, which was situated in the well on the "Kosmostantsiya" territory near the Keminsky and Vernensky catastrophic earthquakes sources.

– Seven days before and during the earthquake (30 December 2017) by M = 3.3 magnitude using this new complex of measuring equipment revealed simultaneous abnormal effects in the acoustic pulses and temperature variations.

– We had a unique event when the earthquake took place near the measuring well (5.3÷7.2 km). Consequently, we have demonstrated high sensitivity of the measuring complex towards the weak earthquake preparation.

– Near disposition of the earthquake's focus to the well was confirmed by the infrasonic measurements on the Orbita Radiopolygon while registering exchange waves after the main shock.

Registration and investigation of the radio emission from EAS. Registration of radio-emission generated by particles of high-energy extensive air showers (EAS) has a number of advantages over other methods of primary cosmic ray investigation, both of which are based on direct registration of shower particles (a relative simple and cheap radio-detector system compared with wide-spread electronic detector systems, the large spatial volume of the space controlled by a single radio antenna, a sensitivity to the characteristics of longitudinal EAS development), and the methods connected with the registration of Cherenkov and fluorescent EAS emissions in ultraviolet and optic diapasons (an unrestricted duty cycle of radio installation which is independent of daytime and weather conditions).

During the measurements searching for EAS connected radio-signals at Tien Shan four radio antennas are used as detectors of Almarec which are oriented to the north-west and north-east. Each antenna station is located at a distance of 30 m from the registration point in the north, south, west, east direction and has two perpendicular loop antennas of the SALLA type, which allow to restore the polarization of the electromagnetic wave. Setting up a radio-signal registration system mostly sensitive in the 30-80 MHz radio frequency range. This system is aimed for simultaneous operation with the EAS particle density and Cherenkov radiation detectors which are present at the station, and will permit a mutual calibration of all these independent methods of EAS investigation.

As a result of the preliminary experiment, which was made using a newly installed dipole radio-antennae set, some candidate events were selected which demonstrate the presence of a noticeable radio-signal pulse in closest 1–3 μs vicinity of EAS arrival time. Specific features of particle density distribution in these events permit to state that most of them have a rather high primary energy E0> $(2–5)\cdot10^{16}$ eV and a close location of their shower cores near to the radio-antennae set, so the time coincidence of the observed radio-pulse with the shower front arrival time in these events cannot be fully accidental. Hence, the radio-antennae system installed at Tien Shan together with a designed program complex for registration of its signal do indeed ensure an effective selection of radio-emission from EAS particles. Later on, with the use of an EAS radio-emission registration method, an enlargement of the energy range of primary cosmic ray investigation at Tien Shan up to $E_0 \sim 10^{19}$ eV is anticipated.

Studying electric storm phenomena on the Tien Shan high-mountain scientific station of the cosmic rays. TShHSS is located as high as the level of clouds passing and during summer thunderstorms the station becomes inside the thunderstorm phenomena. For the spatial (by horizontal and vertical) and temporal investigation of the electronic and gamma radiation from the thunderstorm clouds [46,47], nine points for registering radiation were created in which different detectors were used (figure 12). As can be seen from Fig.12, the registration points were located in the gorge along the arc by ~ 2 km length and from 0 to +540 m along the altitude from the 3340 m mark.

Main systems for registering thunderstorm phenomena. The measuring complex of the Tien Shan station is composed of the following detector systems [48]:

- shower triggering system made of distributed across the station territory hodoscopes on gas-discharge counters SI5G, which registers a moment of the broad atmospheric shower transmission and

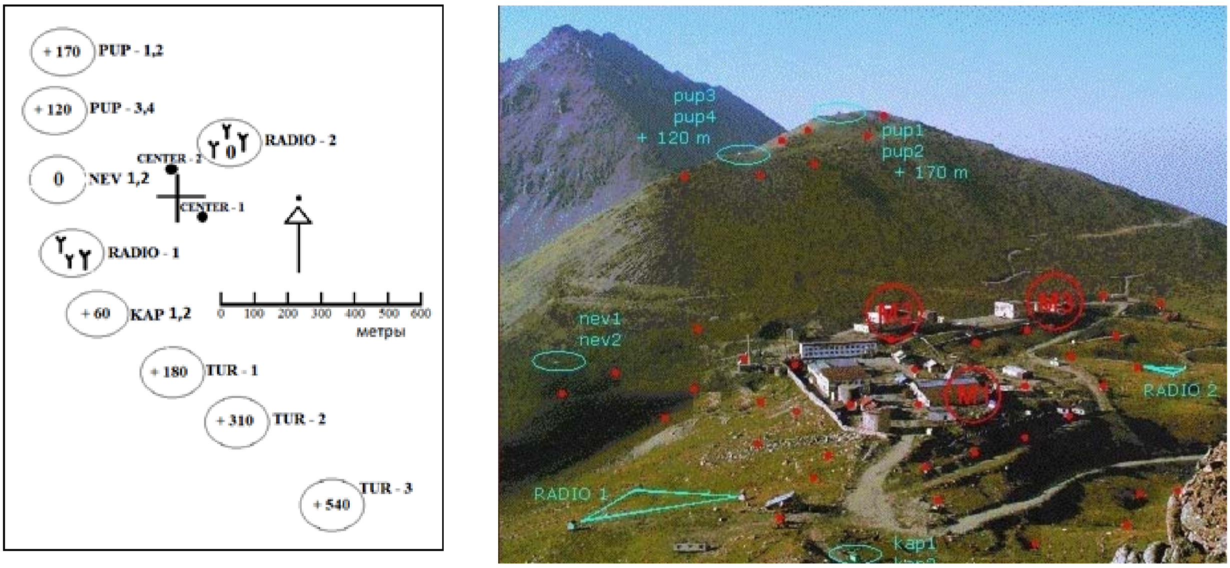

Figure 12 – Disposition of detectors layout on TShHSS
for the thunderstorm phenomena registration

allows estimate its size and cosmic rays primary particle energy by coincidence of signals from different group counters;

- the scintillation system of detectors on the NaI (TI) crystals for registering soft gamma- and hard roentgen radiation intensity from thunderstorm clouds with time resolution from 100 μs to 1 minute in the six energy ranges from 20 keV to 5 MeV;

- Multiple-row spectrometers of internal absorptance were composed of disposed one above another gas-discharge counters hodoscopes interleaved by the thin layers of absorbent (rubber, lead and iron). The spectrometers served for registration of electrons accelerated in the thunderstorm clouds electrical field and emitted by them gamma- and roentgen quanta and also for estimation of their energy by absorption curve;

- muonic detector was composed of proportional counters disposed in underground placement at a depth of 2000 g/cm^2 with 100 m^2 total sensible area, which used for EAS muonic component registration;

- a system of the high-energy and thermal neutrons intensity monitoring, including HM64 neutron supermonitor, was supplemented by the spectrometer on sensible to neutron radiation scintillation counters, neutron monitor on CHM15 counters in the underground placement and separated detectors on the base of CHM17, CHM18, “Helium 2” distributed across station territory;

- two independent radiosystems were operating in the frequency range of 0.1÷30 MHz and at 250 MHz. The systems were used for registering radio radiation with high temporal resolution (200 ns), which was generated in the thunderstorm clouds at striking and also for determining a direction on discharge location by the relative radio signals delay;

- detector of rapid change (jump) of the static electrical field and its high-frequency component (return lightning stroke). During the lightning discharge moment, this detector produces a control signal (trigger) for the whole complex of the measuring equipment.

Since all measuring systems were intended to work directly inside of the thunderstorm cloud, in the conditions of high electromagnetic interference from striking, the impulse signal transmission from detectors to the registration centers is implemented along shielded cable (of 3 km in length) using transmitting and receiving amplifiers implemented by vacuum electronic lamps.

For registering the radiation sourced from thunderstorm clouds, the two types of completely different detectors were used on the experimental complex installations: hodoscopes on gauzy ionization counters SI5G and scintillation detectors on the base of NaI(Tl) crystals. During the thunderstorm seasons, the measurements are conducted continuously, with permanent recording of the signals intensity current values onto the hard-disc of controlling LCU computer.

Studying lightning formation processes with simultaneous registration of different types of radiation: electrons, gamma- and roentgen radiation. Gamma- and roentgen radiation bursts from the thunderstorm clouds, finding which is the goal of measurements, can occur as a result of emergence of the energetic electrons avalanche, accelerated by the thunderstorm cloud electric field. The inoculating electrons with the minimum required energy for acceleration can emerge inside of this cloud, particularly during transmission through atmosphere of the extensive air showers (AES), which are generated by energetic particles of cosmic radiation (with energies above 1 ÷ 10 PeV). The conditions for the scanning system's triggering signal generation were chosen in accordance with the expected burst generation physical mechanism: high strength electric field in the experimental installation disposition region, and striking and shower electrons from passing AES. In order to satisfy these conditions, three types of trigger signals were used in the experiment [49].

Firstly, the trigger signal was received by the data collection system from the local electric field strength sensor, which was located near the scintillation detectors system center (approximately in the middle of between NEV and KAPT points in the figure 12). Since the rapid field drop (during μs) in the installation region should be accompanied by the striking, this trigger was generated in the moments of the field strength jumping ("bounces") and corresponded closely to striking.

Secondly, as the trigger signal we used an electromagnetic pulse (EMP) which, as it turned out in the process of measurements, was directed by striking on the long signal cables, connecting remote points of detectors location (figure 12 – KAPT, TUR1, TUR2 and TUR3) with the registration center. After appropriate amplification, this pulse was sent to the temporal scanning system and initiated recording of the scintillation signals intensity during the striking inside the thunderstorm cloud.

Thirdly, for registering the EAS transmission moments we used a signal from shower trigger system, which also caused conservation of the information about scintillations intensity near this moment. In order to reduce intensity of the shower trigger signals with simultaneous increase in the energy of the primary particles average, we used signals of the fourfold coincidence between separate detectors of this subsystem for the trigger signal generating.

Registration of Striking by ionization spectrometer. For investigating the registered charged particles and gamma-quanta energy spectra we used a multilayer ionization spectrometer, presented in Fig. 13. One small premise could house three modules. In one module four layers with 60 counters each were situated (figure 13). Between counters there were absorbers, which are the lead layers and rubber rich by carbon. Such multilayer system composed of the ionization counters and absorbers transforms the installation from the simple radiation detector to the spectrometer of full absorption which allows estimate energy spectra of registered charged particles and gamma-quanta by signals intensity correlation in different layers of counters [50].

Since the coefficient of absorption of gamma-quanta in the photoeffect region strongly depends on the absorbent atomic number, the filters composed of different substances provide different threshold energy of gamma radiation, registered in each layer of the spectrometer, and gives full energy spectra of the registered charged particles and gamma-quanta.

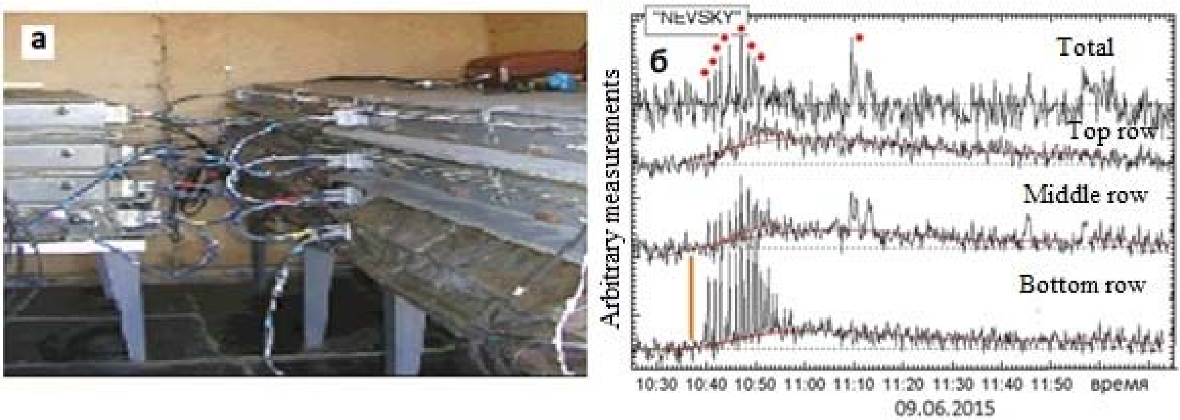

Figure 13 – A multilayer spectrometer for radiation energy estimation during thunderstorm phenomena. The measurement results by ionization spectrometer

Figure 13 depicts the result, which was obtained on the ionization spectrometer at the thunderstorm time on 9 June 2015. The electrons registration continued during an hour and a half from 10.30 a.m. to 12.00 p.m. The burst maximum was observed at the lightning, which happened at 10.48 a.m. With an account of thickness of ionization spectrometer adsorbent as well as the absorption curve, we can estimate energy of electrons as the value no less than 12 MeV. Observing energetic electrons at short bursts and specific features of these bursts (quasi-periodical structure of the radiation intensity at the burst time and the bursts timed to the moments with the electric field maximal strength) enable us interpret short burst of radiation as a direct experimental observation of the particles, accelerated in the thunderstorm cloud electric field.

Registration of striking by the scintillation detector. When passing through scintillation crystal, the charged particles or a gamma-quantum generate pulses of variable amplitude, where the scintillation pulse value is proportional to the energy scattered by registered particles inside the crystal. In figure 14, we show the registration point with scintillation detector and a result of its operation. The scintillation detector pulse carries important information. It is proportional to the energy of the absorbed inside the spectrometer gamma-quantum in the wide range of amplitudes. To use this information when working with scintillation signals, it is necessary to use a certain amplitude analysis method. For this goal during the experiment, fast parallel amplitudes discriminators were used. The threshold levels, at which the discriminators are triggered, are adapted by the potentiometers "Porog" by the ascending values: 0.1, 0.2, 0.4, 1.0, 2.0 and 3.5B. The counting circuits of the data collection system allows define intensity of the signals separately for each amplitude interval between these values (the last sixth interval do not have the upper bound and correspond to all input pulses with the amplitude >3.5V). This way the system approximately estimates the type of the amplitude spectrum of the registered gamma radiation.

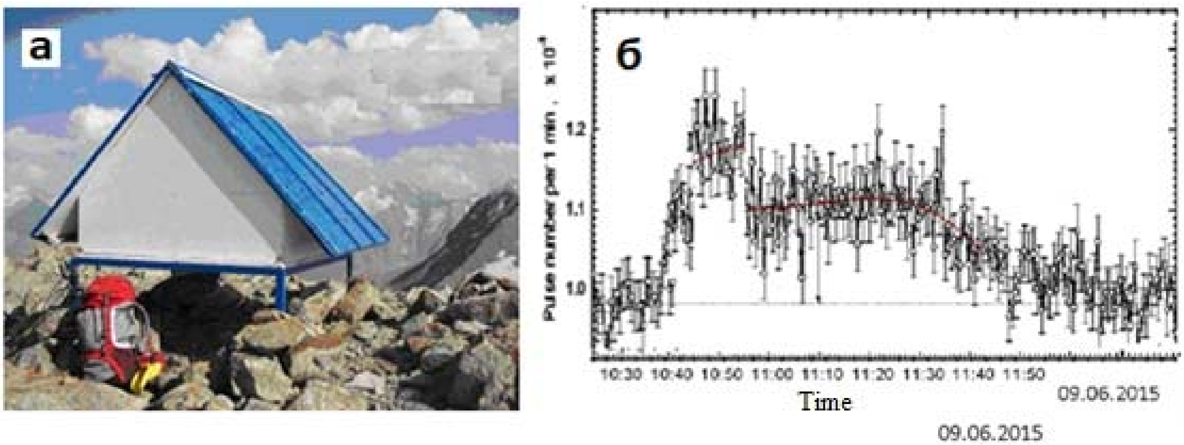

Figure 14 – A gamma radiation registration point (a) and measurement results with scintillation detector (b)

Figure 15 shows the result received on scintillation detector during the thunderstorm on 9 June 2015. As can be seen from figure 14, the lightning flash was registered in the detectors simultaneously. Unlike the ionization detectors, the relative value of increase in the scintillation signals intensity was equal to ~ 15%, that is greater by one order of magnitude than for the ionization counters, in spite of substantially smaller (twentyfold) area of the scintillator sensible surface.

It was established that long-period increases were induced precisely by gamma radiation to which the crystalline scintillators are particularly sensible. This circumstance confirms the conclusion about stipulation of such bursts by accelerated charged particles, i.e. electrons, as well as by its X-ray bremsstrahlung. With an account of thicknesses of ionization spectrometer's absorber and the absorption curve, one can estimate the electrons' energy, which in this case no less than 12 MeV.

Conclusion. Today, in high-energy physics there are several strongly different phenomenological models of the hadronic interactions are used, each of which claims for adequate description of hadron-nucleus interaction at the extra-high energy. Their difference leads to significantly diverse conclusions about nature of coplanar generation of the most energetic particles that are parts of the extensive air shower (EAS) trunks. The latter cannot be described by the hadronic interactions conventional models, i.e. events of “centaur” or “anti-centaur” types with the anomalous high part energy, released in the charged component, or on the contrary, in the neutral component. Observation of abnormally weak absorbing hadrons permitted to raise a question about the cosmic rays (CR) long-range nuclear-interacting component in the region of the spectra breaking in the mass composition of the primary cosmic rays (PCR). The latter consequently resulted from solving an inverse problem, which is recovering spectra parameters and PCR composition by EAS observed characteristics.

Since the problem of PCR composition at the ultrahigh energy is far from being solved, the initial goals set for EAS complex installations are as relevant as before. But now this problem can be solved in a more effective way, if we base not only on high level of understanding of the problem but also on the progress of the last decades in the field of experimental and computer technologies, which allows us use new methods of the experimental data processing and analysis. Precisely such an approach is laid as a foundation in the installations that are located on Tien Shan high-mountain scientific station, which, as we understand, are able to make a significant headway in solving classical problems (studying the PCR parameters and building interaction model), which as before, remained unsolved by the complex installations of the EAS registration.

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БИІК ТАУЛЫ ТЯНЬ-ШАНЬ ҒЫЛЫМИ СТАНЦИЯСЫНДАҒЫ ҒАРЫШ СӘУЛЕСІНІҢ ФИЗИКАСЫ МЕН АСТРОФИЗИКАСЫНА БАЙЛАНЫСТЫ ІРГЕЛІ ЗЕРТТЕУЛЕР

Аннотация. Жұмыста Физика-техникалық институттың биік таулы Тянь-Шань ғылыми станциясында ғарыш сәулелерінің физикасы мен астрофизикасы туралы көптеген зерттеу құрылымдарымен бірлесе орындаған зерттеу бағыттарының нәтижелері баяндалады. Зерттеу жұмыстарының басты бағыттарын құраушы негізгі бөлімдер: «Горизонт-Т» қондырғысының көмегімен энергисы 10^{17} эВ жоғары деңгейдегі ғарыш сәулелерінің құрамында орын алатын жаңа физикалық процестерге зерттеулер жүргізіледі; тасқындарды тіркеуші қондырғыларда ғарыш сәулелерінің бастапқы спектрінің «сыну» кеңістігіндегі (10^{14}–10^{17}эВ) ауқымды атмосфералық тасқындардың қасиеттері зерттеледі;

«Адрон-55» қондырғысымен энергиясы жоғары, ауқымды атмосфералық тасқынның алдыңғы конусында пайда болатын бөлшектердің құрылымдық талдауы зерделенеді және энергиясы 0,5 ТэВ жоғары ғарыштық гамма-сәулелерінің көздері іздестіріледі; «Радио-3» қондырғысының көмегімен ауқымды атмосфералық тасқын кезінде туындайтын радио диапазондағы толқындар тіркеуден өткізіеді; «Гроза» қондырғысымен Тянь-Шань биік таулы станциясы маңайында күн күркіреуі кезінде орын алатын электрлік процестер талданады; сейсмикалық белсенділігі басым Алматы аймағындағы жер қыртысының кернеулігін зерттеу жұмыстары ғарыш сәулелерінің құрамындағы жоғары энергиялық мюондарды тіркеу арқылы орындалады.

Түйін сөздер: ауқымды атмосфералық тасқындар, мюондар, гамма-сәулесінің көздері, радиотолқындар, нейтрондар ағыны, сеймикалық белсенді аймақ, жер қыртысының кернеулігі.

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ПЕРСПЕКТИВНЫЕ ФУНДАМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ПО ФИЗИКЕ И АСТРОФИЗИКЕ КОСМИЧЕСКИХ ЛУЧЕЙ НА ТЯНЬ-ШАНЬСКОЙ ВЫСОКОГОРНОЙ НАУЧНОЙ СТАНЦИИ

Аннотация. В работе представлены научные направления по физике и астрофизике космических лучей, проводимые на Тянь-Шаньской высокогорной научной станции Физико-техническим институтом в сотрудничестве с другими исследовательскими группами. Программа исследований содержит следующие основные разделы: на установке «Горизонт–Т» проводится изучение новых процессов в космических лучах при энергиях выше 10^{17} эВ; на ливневой установке исследуются свойства широких атмосферных ливней в области излома первичного спектра космических лучей (10^{14}–10^{17}эВ); на установке «Адрон-55»ведется поиск структур в распределениях частиц из переднего конуса широких атмосферных ливней при высоких энергиях и и изучаются гамма источники космического излучения с энергией выше 0,5 ТэВ; на установке «Радио-3» регистрируются радиоизлучения от широких атмосферных ливней (ШАЛ); на установке «Гроза» проводится исследование грозовых явлений на Тянь-Шанской высокогорной научной станции космических лучей; степень напряженности в земной коре Алматинского сейсмоактивного региона исследуется с привлечением метода регистрации мюонов космических лучей высоких энергий.

Ключевые слова: широкие атмосферные ливни, мюоны, гамма-источники, радиоизлучение, потоки нейтронов, сейсмо-активный регион, степень напряженности земной коры.

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