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S N Vernov and cosmic ray research in Yakutia

E G Berezhko, G F Krymsky

The 100th anniversary of the discovery of cosmic rays will be celebrated soon. Many lines of inquiry related to cosmic ray physics were elaborated by S N Vernov and his colleagues, disciples, and successors. When S N Vernov commenced his investigations, it had been only 20 years since cosmic rays had been discovered, and not so much was known about them. It was unknown whether they are composed of charged particles, how big their masses and charges are, or when and where cosmic rays originate. In his groundbreaking studies, S N Vernov answered some of these questions, while the answers to other question were searched for, were found, and are still being found by numerous colleagues and successors who belong to his scientific school.

Establishing this school and supporting appropriate studies in different regions of the USSR and abroad consumed much of Sergei Nikolaevich's time and seething energy. We consider it our duty to describe a part of this huge work, namely, establishing cosmic ray studies in one of the most remote regions of the country — Yakutia (the Sakha Republic).

These studies were initiated in the pre-war period, owing to the enthusiasm of young Yu G Shafer, who had graduated from Tomsk University. In 1938, Yu G Shafer commenced studies of cosmic rays at the Physics Department of the Yakutsk Pedagogical Institute. Together with the director of this institute, he sent a letter to the P N Lebedev Physical Institute (LPI) in Moscow. The letter was addressed to D V Skobeltsyn and reported that the institute has approved a plan of scientific research work on cosmic ray physics for 1939. The plan included the registering of cosmic rays and correlating these data with the barometric, temperature and geomagnetic measurement results and the intensity of solar radiation, as well as with the phenomena of auroral emissions at the latitudes of Yakutia. In the letter it was also mentioned that a provisional consent was given that D V Skobeltsyn and S N Vernov "will provide advice for this work in writing and also provide strong encouragement." The authors asked D V Skobeltsyn "to support this topic, which is included in the institute's plan of scientific research work, in the RSFSR People's Commissariat of Education if it is necessary." From that time, S N Vernov was for many decades a scientific leader of these studies in Yakutsk.

In 1947, the Yakutsk Research Base of the USSR Academy of Sciences (USSR AS) was established. The Chairman of the USSR AS Council of Branches and Bases, Academician V G Volgin, wrote to the President of the USSR AS S I Vavilov: "When determining the structure of the Yakutsk Base of the Academy of Sciences of the USSR, it was taken into account that the Lebedev Physical Institute of the USSR AS, the Institute of Terrestrial Magnetism of the Main Directorate of Hydro-Meteorological Services of the USSR Council of Ministers, the 2nd Scientific Research Institute of Physics of Moscow State University, and research fellows of Yakutsk research institutions recommended including cosmic ray studies on the scientific program of the Base and to establish a cosmic ray Station at the Yakutsk Research Base of the USSR AS." Yu G Shafer, who was back from the front, was recommended to pursue these studies. On 25 December 1947, the Presidium of the USSR AS issued an order whereby the Scientific Council of the Yakutsk Base was approved, consisting of 30 members. Doctor of Physicomathematical Sciences S N Vernov was a member of the Council.

Also in 1947, Academician V G Volgin and the Director of the Scientific Research Institute for Terrestrial Magnetism [now N V Pushkov Institute of Terrestrial Magnetism, the Ionosphere, and Radio Wave Propagation (IZMIRAN in *Russ. abbr.*) of the Russian Academy of Sciences] N V Pushkov addressed Academician S I Vavilov and substantiated the necessity of deploying a network of stations on the territory of the USSR for continuous registering of cosmic rays by sensitive instruments to be purchased in the USA. Since attempts to purchase this equipment (ionization chambers) failed, it was decided to develop them independently in the USSR. Yu G Shafer was charged with doing that in the Laboratory of Cosmic Rays at the Research Institute for Nuclear Physics (RINP) of Moscow State University (MSU). From the very beginning, this activity was supported by S N Vernov. Designing and technological resources available at RINP were involved in this work. The engineering part of the work was directed by the Head of the Workshop, A S Muratov. N L Grigorov, who had experience in the development and manufacturing of high-precision torsion

E G Berezhko, G F Krymsky Yu G Shafer Institute of Cosmophysical Research and Aeronomy, Siberian Branch of the Russian Academy of Sciences, Yakutsk, Russian Federation
E-mail: berezhko@ikfia.ysn.ru, krymsky@ikfiaa.ysn.ru

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electrometers of a unique design, was also involved. In his memoirs he wrote: "A developmental prototype S-2 was designed and manufactured in 1947–1948. It was a 20-litre spherical chamber made of steel and filled with chemically pure argon. A compensation chamber was placed inside the main chamber, and the ionization current was carried in the former by beta particles from a radioactive substance. The compensation current had the same value as the current produced by the cosmic rays in the main chamber, but its flow direction was opposite. Hence, the device measured deviations of the cosmic ray-produced ionization current from an average value, which was compensated for by the current in the compensation chamber. This so-called null method provided high sensitivity of the device."

In 1948, the developmental prototype of the ionization chamber was successfully tested in Yakutsk. In 1950, the Stalin Prize was awarded to Yu G Shafer, N L Grigorov, and A S Muratov for the design and manufacture of this device.

Based on the prototype, two ionization chambers, ASK-1 and ASK-2, were developed, with volumes of 900 and 50 litres, respectively. In 1950–1952, the Fizpribor plant made the first run of the production items, which were installed at nine Soviet stations for cosmic ray observations.

These sensitive chambers operated for more than 30 years at several stations, and the ASK-1 device installed in Yakutsk in 1953 is still operational! The network of stations, in addition to its scientific significance, played the role of a catalyst promoting scientific research work on the vast territory of the USSR.

Already during the first working period of the new equipment in Yakutsk, it was possible to test in detail E L Feinberg's and L I Dorman's theory of meteorological variations of cosmic ray intensity. The sharply continental climate of Yakutia favored studies of the seasonal variations predicted by the theory. The reason for these variations is as follows. The thickness of the atmosphere increases with its temperature, and muons created in its upper layers due to collisions of cosmic rays with atmospheric atoms have a higher probability of decaying when moving to the chamber; hence, their flux decreases.

Variations in the cosmic ray fluxes measured by the ionization chamber were observed during transits of cyclones and geomagnetic storms. Periodic variations with the period of 1 solar day were also detected. It was hypothesized that these variations are caused by atmospheric temperature variations as well. However, A I Kuz'min showed using the data on temperature monitoring in Yakutsk and a theory of meteorological effects that the influence of the temperature results in increased amplitudes of the diurnal variations rather than in decreased ones. It was, therefore, proved that the device observed the anisotropy of cosmic rays [1].

For many years, A I Kuz'min and his disciples conducted experimental and theoretical studies of the cosmic ray anisotropy and its physical origin and consequences. For this purpose, they developed muon telescopes which consisted of Geiger–Müller gas-discharge counters. The counters were placed in trays (several counters in each tray) and the trays were arranged in a stack with three horizontal arrays, one over another. A coincidence scheme selected simultaneous detections by all three arrays. The trays were combined in such a way that the coincidence scheme selected muons coming from north or south (east or west). Each such combination of trays was called a muon telescope. Telescopes that detected muons arriving from north and south formed a system of 'crossed' telescopes. The crossed telescopes were installed on the ground and in a mine tunnel at a water-equivalent depth of 7, 20, and 60 m (the actual depth was less, approximately by a factor of 1.8). The Yakutsk underground array of crossed telescopes allowed performing precise measurements of the cosmic ray anisotropy and its energy spectrum, as well as of spectra of other variations in the cosmic rays.

The complex of crossed telescopes allowed observing cosmic ray intensity diurnal variations caused by the anisotropy of cosmic ray angular distribution in the near-Earth space. These variations, unlike other variations, including meteorological ones, had different amplitudes and phases when measured by different telescopes. If the telescope geometry is known, it is possible to determine the exact parameters of the anisotropy. Studies of the anisotropy and its temporal variations allowed revealing its physical origin. On the average, the observed anisotropy is caused by the excess of particles arriving at the evening side of Earth. It can be interpreted in terms of the cosmic ray transport by the solar wind with the frozen-in interplanetary magnetic field [2]. Due to such transport, an ordered motion of cosmic ray particles develops in the radial direction from the Sun. The resulting deficit of cosmic rays in the inner Solar System is compensated for by their diffusion in the opposite direction. If the interplanetary magnetic field had been totally random (turbulent), the diffusion would also have created a radial ordered motion of the cosmic rays to the Sun. As a result, the anisotropy would not exist in a stationary state. However, the interplanetary magnetic field has a regular component, which is extended in the radial direction and twisted to an Archimedean spiral by the solar rotation. That is why cosmic ray diffusion occurs predominantly at an angle to the radial direction. The radial diffusion is compensated for by the convective outflow of cosmic rays with the solar wind, while the tangential component of the diffusion flow, which is perpendicular to the line between Earth and the Sun, is uncompensated. Theoretical estimates of this effect gave a magnitude which was less than the experimental finding by 15–20%.

The paradox is resolved by taking into account the adiabatic change in the energy of fast charged particles as they propagate in a scattering medium: the particle energy decreases in an expanding medium, and increases in a compressing one.

The solar wind plasma expands everywhere. Therefore, the cosmic ray particles lose their energy within Earth's orbit, and this additionally contributes to their deficit. Compensation for the deficit due to enhanced diffusion solves the problem. This solution led to a correct transport equation for the cosmic ray distribution function $f(\mathbf{r}, \mathbf{p}, t)$ [2]:

$$\frac{\partial f}{\partial t} = \nabla(\varkappa \nabla f) - \mathbf{w}\nabla f + \nabla \mathbf{w}\, \frac{\mathbf{p}}{3} \frac{\partial f}{\partial p} \,.$$

Here, t is the time, $\mathbf{r}$ is the radius vector, and $\mathbf{p}$ is the momentum of the cosmic ray particles. The first term on the right-hand side describes the spatial diffusion of cosmic rays with the diffusion tensor $\varkappa$. The second term is responsible for the convective transport due to the motion of the scattering medium with a velocity $\mathbf{w}$. The third term describes the adiabatic change in the cosmic ray energy in the compressible medium. Somewhat later, this equation was derived by E Parker [3], and then by A Z Dolginov and I N Toptygin [4], who applied a fully kinetic approach.

It turned out that the transport equation can describe the particle acceleration in media that contract rather than expand. Such a situation occurs at the fronts of shock waves, where the conditions favor the regular acceleration of cosmic rays, which is the most efficient acceleration. When the problem of charged particle acceleration by a strong shock wave was solved [5], S N Vernov appreciated this result at its true value and presented this paper to the journal *Doklady Akad. Nauk SSSR* (*Sov. Phys. Dokl.*). It is worth noting that S N Vernov had experts substantiate this decision. Most commonly, the experts worked at the MSU RINP. In this case, it was Boris Arkad'evich Tverskoy who directed Vernov's attention to this solution. The discovered mechanism of regular particle acceleration can be widely applied to cosmic ray astrophysics (see, e.g., review [6]). The development of the theory of regular acceleration of the cosmic rays in supernova remnants, especially of the nonlinear theory [7] that consistently takes into account the backaction of the accelerated particles on the structure and dynamics of the shock front, strongly supports the hypothesis that the observed spectrum of cosmic rays with energies of up to 10^{17} eV is formed in the galactic supernova remnants (see reviews [8, 9]). It is important to note that the nonlinear theory is able to predict in detail the properties of supernova-remnants nonthermal emission due to the cosmic ray particles accelerated in remnants. Comparing theoretical predictions for a particular remnant with observations, which are performed in a wide range of wavelengths (from radio up to gamma-ray range), it is possible to obtain crucial evidence related to both the nature of the nonthermal emission of the remnants and the origin of the observed cosmic ray spectra. For instance, Figures 1 and 2 plot the results of calculations of the photon energy dependence of the nonthermal emission energy flux for the RXJ1317.7-3946 and SN 1006 supernova remnants together with the observations. It is seen that the theoretical results are in good agreement with the experimental data. This led to the conclusion that the remnants of interest effectively produce cosmic rays, thereby confirming the idea that galactic supernova remnants are the sources of cosmic rays with energies of up to 10^{17} eV.

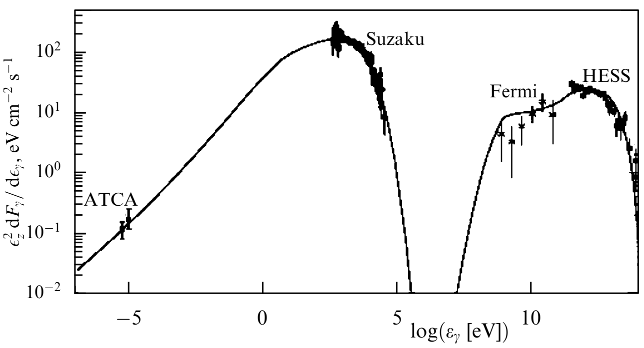


Figure 1. The energy flux for the nonthermal emission of the RXJ1317.7-3946 supernova remnant versus the photon energy. The calculations were performed in the framework of the nonlinear kinetic theory for cosmic ray acceleration [10]. The results of measurements of the radio emission [Australia Telescope Compact Array (ATCA)], X-rays (Suzaku space observatory), and TeV emission [HESS system of gamma-ray telescopes (High Energy Stereoscopic System)] are also shown. The GeV-emission data obtained by the Fermi Gamma-Ray Space Telescope in 2009 are also presented.

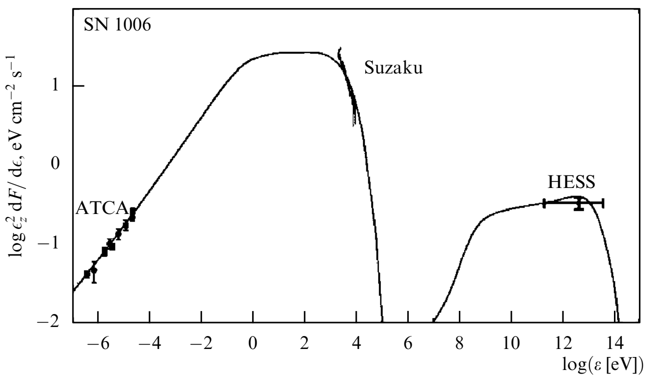


Figure 2. The energy flux for the nonthermal emission from the SN 1006 supernova remnant versus the photon energy. The calculations were performed in the framework of the nonlinear kinetic theory for cosmic ray acceleration [11]. The results of measurements of the radio emission (ATCA radio telescope), X-rays (Suzaku space observatory), and TeV emission (HESS system) are also shown.

The registering of cosmic rays by the ASK-1 chamber in Yakutsk led to the initiation of studies in another important area. The ionization current in the chamber, which is registered by the chamber electrometer, sometimes undergoes abrupt increases. In the records, they look like discontinuities or spikes. When studying cosmic ray variations, such spikes are considered to be noise and are removed on treating measurement data. D D Krasil'nikov, who was a research fellow of the Institute of Cosmophysical Research and Aeronomy (ICRA) at the Yakutsk Branch of the USSR Academy of Sciences, noticed these spikes and commenced studying them. The amplitude spectrum of the spikes turned out to be power-law, with the exponent close to that for the cosmic ray energy spectrum. The spikes are caused by secondary particles that are created in interactions of nuclear-active particles (predominantly pions) with the chamber walls, as well as by electromagnetic cascades caused by bremsstrahlung photons produced by high-energy muons. Employing special tricks, D D Krasil'nikov filtered out the spikes of nuclear-active origin and studied muon spikes. The interest in cascade processes inspired him to create a small experimental array for studying extensive air showers (EASs). The array consisted of only three trays with Geiger–Müller counters. Later on, the array was extended to 5 pavilions on a site of about 1 hectare. Careful data processing allowed determining the upper limit of the anisotropy of 10^{15}-eV particles with an accuracy of better than 0.1%; it was the best result for that time (1967).

In the 1950s, typical EAS arrays became more informative and covered a larger area. The biggest arrays in the USSR were the MSU RINP array and LPI array installed in Tien Shan; the studies were directed by G B Khristiansen and S I Nikol'sky, respectively. At that time, there were EAS arrays abroad covering areas of more than 10 km^2. As early as 1963, Sergei Nikolaevich Vernov initiated the development of an array that was competitive with the best foreign counterparts. He performed the overall direction of the design. S I Nikol'sky and G B Khristiansen also took an active part in this work. The work became much more active when relict radiation was discovered and it was predicted that a blackbody cut-off exists in the cosmic ray spectra at an energy of

6×10^{19} eV. This cut-off inevitably arises due to cosmic ray energy losses as a consequence of the ray interaction with the relict photons provided that the cosmic rays of extreme energies originate outside of the Galaxy. Yakutsk was selected as the place for the array development. The weighty argument in favor of this decision was related to the experience accumulated at ICRA and the available qualified human resources. As often happens, making a decision about the financial support of the studies was not easy and required significant efforts, mainly of S N Vernov. It is sufficient to mention that the first response by M A Lavrent'ev, who was the Chairman of the Siberian Branch of the USSR AS, was not favorable enough. The positive decision about the construction of the Yakutsk EAS array was obtained to a large part due to the active position of S N Vernov. He met the leaders of the USSR AS SB many times, and organized an extensive discussion of the problem by the scientific community. In connection with this, it is worth citing the letter from V L Ginzburg to the Vice President of the USSR AS B P Konstantinov: "Dear Boris Pavlovich! As I have been informed, you would like to know my opinion on whether it is expedient to construct a big array for studies of extensive air showers in Yakutsk. My attitude to this project is very positive... Finally, to the point, the Yakutsk array will be able to measure spectra in the range of $3 \times 10^{17} - 10^{20}$ eV, where data are almost absent and where we may expect a substantial contribution of the metagalactic component... Thus, the construction of this array is a 'good business': it is important not to be late and to launch it as soon as possible and, in addition, to have a plan for its extension to 10^{21} eV. Sincerely yours, V L Ginzburg. 29 January 1968."

Vernov's efforts were successful: on 11 April 1968 the State Committee for Science and Technology of the USSR Council of Ministers issued resolution approving the construction of the Yakutsk EAS array. The tasks for the Institute were formulated, and human and other resources for the construction were specified. More than 200 institutions were involved in the array development in one form or the other. Sometimes, S N Vernov took part in meetings with the leaders of these institutions.

The Yakutsk EAS array was opened for operation on 14 April 1973. The array can be considered as a set of observational stations which are distributed over an area of 20 km^2 (by now the area has been diminished to 12 km^2) and working in coordination. The EAS registering is aimed at determining the following main characteristics of cosmic rays with energies above 10^{15} eV: the energy spectrum, anisotropy, and the mass composition. A peculiarity of the Yakutsk air shower array is that it has detectors for all the main components of the EASs, i.e., for the electron–photon and muon components, and for Cherenkov radiation.

Since Cherenkov radiation is integrated over the entire altitude of the atmosphere, its registration allows one to estimate rather precisely the total energy of electrons in a shower and, hence, to obtain a reliable estimate of the energy of a primary particle. These measurements also make it possible to calibrate the electron–photon registration channel.

Given the energy of a primary particle, the number ratio of muons and electrons in the extensive air shower it produces is sensitive to the particle mass, thereby allowing an estimation of the mass composition of cosmic rays.

During the almost 40 years of its operation, the array has been upgraded. The next scheduled upgrade is being performed now. The directors of the work at the Yakutsk EAS array, N N Efimov and D D Krasil'nikov, were awarded the Lenin Prize in 1982.

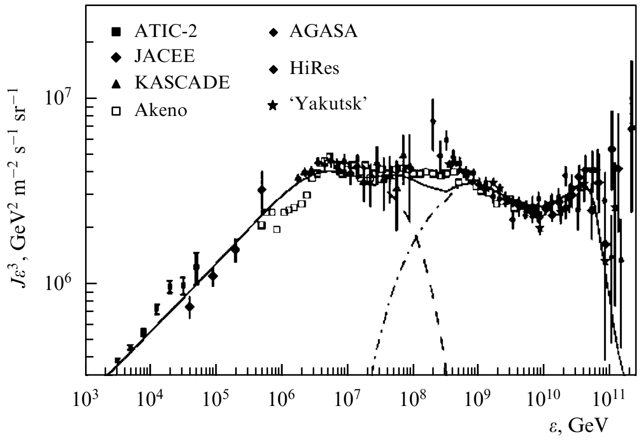


Figure 3. The cosmic ray flux versus particle energy [13]. The dashed line shows the spectrum of cosmic rays produced by galactic supernova remnants; the dot-and-dash line corresponds to the spectrum of rays from extragalactic sources, and the solid line demonstrates the sum of the two. The measurements of balloon [ATIC-2 (Advanced Thin Ionization Calorimeter) and JACEE (Japanese-American Collaborative Emulsion Experiment)] and ground-based KASCADE (KArlsruhe Shower Core and Array DEtector), Akeno, AGASA, HiRes, and 'Yakutsk' ESA experiments are also presented.

One of the main characteristics of cosmic rays observed by air shower arrays is their energy spectrum at particle energies above 10^{15} eV. By the end of the 20th century, a large body of experimental data on cosmic ray spectra for extreme energies had been obtained. The data allowed arguing with confidence that several peculiarities exist in the spectra in the energy range from 10^{15} to 10^{19} eV. In addition to the break (steepening of the cosmic ray spectra at the energy of 3×10^{15} eV; now the break is called a knee or the first knee) that was found in 1958 by research fellows working at MSU RINP and led by S N Vernov, new peculiarities were observed: a second knee at energies of 5×10^{17} eV, and a depression at 6×10^{18} eV (Fig. 3). In these events, data obtained with different air shower arrays [Fly's Eye and HiRes in the USA, AGASA (Akeno Giant Air Shower Array) in Japan, and the Yakutsk array] were in good agreement regarding the shape of the measured spectra; however, they differ in amplitudes and positions of the peculiarities on the energy axis. As has been suggested many times (see, e.g., Ref. [12]), these differences almost vanish if the individual particle energy ε measured in each experiment is replaced by $\lambda\varepsilon$, where λ falls in the range $0.8 < \lambda < 1.2$ (see Fig. 3, which depicts the experimental data obtained with all three air shower arrays mentioned above). Such a procedure is quite appropriate because the accuracy of cosmic ray energies measured in such experiments is about 20%.

Before 2007, the measurements did not allow one to argue unambiguously that a blackbody cut-off in the cosmic ray spectra exists. In Fig. 3 it is seen that the data obtained with the Yakutsk air shower array were not at variance with the existence of the cut-off. However, since the number of measurements is limited for the energies $\varepsilon > 4 \times 10^{19}$ eV, it is difficult to make a definitive conclusion. At the same time, the measurements performed with the AGASA array, whose relative aperture is more than an order of magnitude bigger

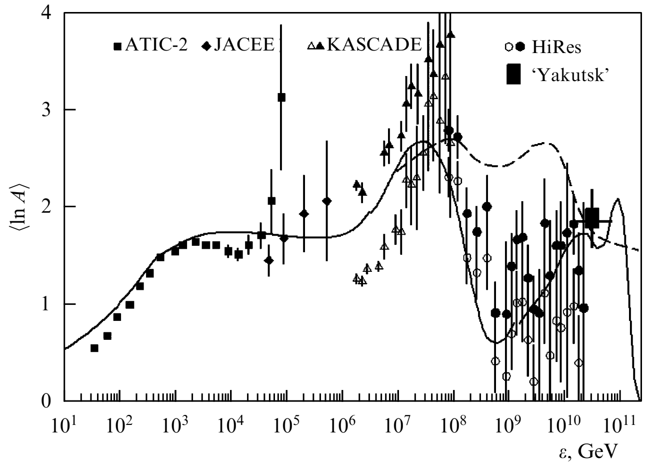


Figure 4. The mean logarithm for the cosmic ray atomic number versus the energy [16]. The solid and dashed lines correspond to different scenarios for the formation of the cosmic ray spectrum for energies $\varepsilon > 10^{17}$ eV. The measurements performed with the balloons (ATIC-2 and JACEE) and with the ground-based arrays KASCADE, HiRes, and 'Yakutsk' (Yakutsk) are also shown [17].

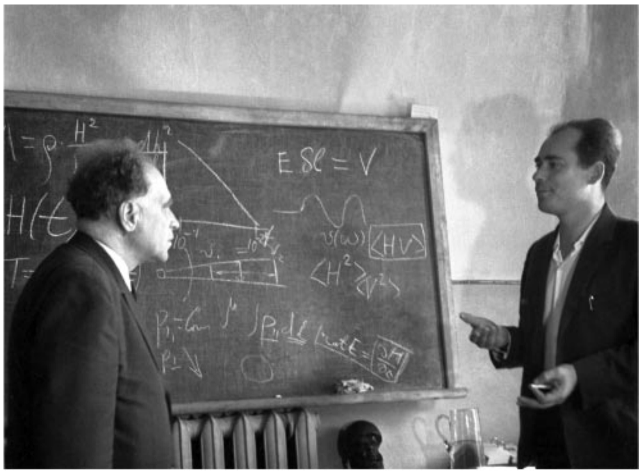
than that of the Yakutsk EAS array, quite definitely favored the absence of any steepening of cosmic ray spectra for the energies $\varepsilon < 10^{20}$ eV. Only in 2007 did the experiments HiRes and Auger proved the existence of the blackbody cut-off quite soundly. This fact quite definitely evidences that the cosmic rays of extreme energies originate from extragalactic sources. Now the search for these sources, measurements of the spectra of the extragalactic component of cosmic rays, and experimental determination of the transition region between these two components in the observed cosmic ray spectrum are on the agenda.

In accordance with energy-based considerations, the most probable sources of extragalactic cosmic rays with extreme energies are active galactic nuclei (see, e.g., Ref. [12]). This hypothesis is favored by the correlations between the directions of arrival of cosmic rays with energies $\varepsilon > 3 \times 10^{19}$ eV and the angular positions of active galactic nuclei, as was established by the Auger experiment [14] and the Yakutsk EAS experiment as well [15].

Two different scenarios for the formation of the overall cosmic ray spectrum exist. In the first one, the extragalactic component dominates for energies $\varepsilon > 2 \times 10^{17}$ eV (see Fig. 3), while in the second scenario it takes place only for $\varepsilon > 10^{19}$ eV. In the latter case, the galactic component dominates in the observed cosmic ray spectrum at energies up to $\varepsilon \approx 3 \times 10^{18}$ eV. It is not clear whether the galactic supernova remnants are able to accelerate the particles to such high energies or an additional source (or reacceleration mechanism) shows its worth in the Galaxy.

It is important that the two scenarios mentioned above predict considerably different mass composition of cosmic rays for particle energies $\varepsilon > 10^{17}$ eV (see Fig. 4, which depicts numerical results for the mean logarithm of the atomic number for cosmic rays versus their energy for the two scenarios). The data are in better agreement with the first scenario. However, rather large uncertainties do not allow one to reach a definitive conclusion. To determine the cosmic ray mass spectrum more reliably, the Yakutsk air shower array is equipped with complementary differential Cherenkov detectors, which can separately detect the Cherenkov radiation arriving from different depths in the atmosphere.

S N Vernov (center) with Yakutsk cosmophysicists: A I Kuz'min to the left of S N Vernov, and G V Shafer and Yu G Shafer to the right (Yakutsk, 1967).



S N Vernov (left) with G F Krymskii at a seminar at the Institute of Cosmophysical Research and Aeronomy (Yakutsk, 1967).

After the establishment of the Institute of Cosmophysical Research and Aeronomy, SB RAS in 1962, its activities were at the center of Sergei Nikolaevich Vernov's attention. The Scientific Council of the USSR Academy of Sciences on Cosmic Rays, where he was the Chair, periodically organized All-Union Conferences on Cosmic Ray Physics in different cities in the country.

In 1967, ICRA organized the next conference due in Akademgorodok near Novosibirsk. S N Vernov conducted a workshop, which was held at the Institute of Nuclear Physics at the time of the conference. Before the commencement of the conference, he visited ICRA and discussed there the problems related to the development of the Yakutsk EAS array.

The All-Union Conferences on Cosmic Rays were held in Yakutsk in 1962, 1977, and 1984. In 1972, a symposium was organized on the site of the already constructed air shower array, with the participation of scientists from different scientific centers of the USSR and East Europe. A wide range of problems on cosmic ray physics were addressed, with the main emphasis on cosmic rays with extreme energies. Sergei Nikolaevich had considered it necessary to make a scientific presentation for the Yakutsk regional committee of the Communist Party of the Soviet Union, where all the

S N Vernov (foreground) with Yakutsk cosmophysicists. From left to right: A I Kuz'min, I E Sleptsov, A S Rymar', V A Orlov, D D Krasil'nikov on the site of the air shower setup (Yakutsk, 1972).

republic authorities were present. He also visited the almost finished by that time Yakutsk air shower array.

In 1976, the Presidium of the USSR AS SB discussed once again the activities of ICRA. S N Vernov, who took part in this meeting, made a presentation and highly appreciated the scientific achievements of the Institute. Under the aegis of the International Union of Pure and Applied Physics (IUPAP), conferences on cosmic rays are organized every two years in different countries. Sergei Nikolaevich personally composed the Soviet delegations for each of the conferences. Beginning in 1959, representatives from ICRA (Yakutsk) have attended all these conferences.

Sergei Nikolaevich in every way promoted cooperation with our colleagues abroad. In 1981, one of the authors (GFK) received an invitation to work at the Institute of Nuclear Physics in Heidelberg as a visiting scientist. Sergei Nikolaevich supported this proposal and the visit was made. In the following years, the cooperation between the institutes became more active and still continues.

In conclusion, it is worth saying that the establishment and development of the fundamental studies on cosmic ray physics in Yakutia were successful thanks largely to the active support and participation of S N Vernov, as well as his colleagues and disciples.

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