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Chapter 16

THE FIRST EXPERIMENTS IN COSMIC-RAY RESEARCH WITH THE AID OF ROCKETS, 1946-1957*

S. N. Vernov and L. A. Vedeshin†

Contemporary science already possesses much data about cosmic rays. We know their composition, energy spectrum, and many physical properties. A number of questions concerning cosmic ray physics, however, remain to be solved.

The study of cosmic rays is important for two fields of science, the physics of high energy-particles, and astrophysics--in particular physics of the Sun and stars. The study of the interaction of particles of super-high energies (10^{12} eV) is presently possible only through analysis of cosmic rays, since particle accelerators of such energies have not yet been created. Astrophysical cosmic-ray research and the energy of these particles in space is of great interest compared with the energy of interstellar magnetic fields, the kinetic energy of particles of interstellar gas, and the energy of stars. Furthermore, cosmic rays bear information about the processes which occur in the interiors of distant galaxies.

The value of cosmic-ray research for studying the physical conditions and processes that take place in Sun and solar system, and also for providing radiation safety of present and future space flight, is enormous.[1] Data about cosmic-ray intensities were first obtained slowly, determined in the coefficients of their absorption in water and the atmosphere, and other different materials.[2]

D. V. Skobel'tsyn obtained fundamental data about new emissions in 1927. With the aid of the Wilson cloud chamber placed into the magnetic field, he established that cosmic rays are the flow of charged particles with energies that exceed many times the energy of particles radiated by radioactive materials, and cause a new physical phenomenon--the formation of showers of particles. Despite the comparatively low flow values of such particles, the findings made it necessary to pay serious attention to their emission. In our country, this problem was dealt with by D. V. Skobel'tsyn, V. I. Veksler, L. V. Mysovsky et al.

Taking into account this cosmic-ray intensity increases considerably with altitude, and the character of cosmic radiation can change as a result of the interac-

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† Academy of Sciences, USSR.

tion of cosmic-ray particles with the atmosphere, recorders were made to be lifted as high as possible above the boundary of the atmosphere. For this purpose, a radiosonde designed by Prof. P. A. Molchanovo was used, which made it possible to transmit to the Earth data about cosmic rays and the readings of a barometer. Electric pulses from the instrument, relayed with the aid of a radio transmitter, were broadcast and recorded at a ground receiving station, and later were deciphered.[3] This method was widely adopted for studying cosmic rays in the stratosphere at altitudes below 30 km. At that time, conducting such experiments beyond the limits of the upper atmosphere was impossible--for we had available only sounding balloons, stratospheric balloons, and aircraft to lift the instruments.

Scientists nonetheless sought to probe beyond the limits of the atmosphere where, as was expected, one might record directly primary cosmic radiation, and that made it necessary to search for new technical equipment capable of raising instruments to altitudes of 30-100 km. These altitudes we could reach only with rockets.

The question of using rocket engineering for conducting investigations in the upper atmosphere was discussed for the first time at the All-Union Conference on the Investigation of the Stratosphere, organized in 1934 by the USSR Academy of Sciences in Leningrad. S. P. Korolev, M. K. Tikhonravov, N. A. Rynin and other specialists at this conference expressed the opinion that the rocket was the only apparatus capable of raising instruments to altitudes considerably in excess of 30 km.[4] This conference helped propagate the idea of creating a stratosphere rocket, and established the first contacts between the physicists and engineering specialists in this new area of technology. It resulted in proposals for such rockets, and a decision of a conference board for the study of the stratosphere with the USSR Academy of Sciences (1934-1938) under the chairmanship of academician S. I. Vavilov.[5]

A number of designs of meteorological and research rockets were developed in the pre-war years, and some of them were constructed. These rockets, however, proved unable to lift scientific instruments to the necessary altitudes, and the war interrupted this activity. In 1943, in spite of the desperate military situation, the P. N. Lebedev Physics Institute of the Academy of Sciences of the USSR (FIAN) assigned to industry the design of a rocket capable of lifting instruments to an altitude of approximately 40 km for the purpose of investigating cosmic radiation. The planned effort, conducted under the leadership of M. K. Tikhonravov and P. I. Ivanov, was completed in 1945. The rocket was a solid-propellant (powder) three-stage vehicle with a diameter of 132 mm, and a length, with the combustion chamber, of 4230 mm (Fig. 1). It possessed a launching weight of 87.2 kg; the weight of the last stage, which reached the peak trajectory, was 14.9 kg with instruments. The rocket was launched from a tower which had guides 10.5 m in length, and according to calculations, would reach an altitude of 48 km when launched from the high-mountain station of the USSR Academy of Sciences in the Pamirs (at an altitude of approximately 4000 m), and reach 35 km when launched from sea level.[6]

At the beginning of 1946, a group was organized in FIAN to develop equipment for determining the intensity of cosmic radiation in experiments on rockets, and that subsequently transmit the scientific information from the rockets to the Earth, including construction of ground stations for receiving and recording these data. The scientific gear developed in FIAN for the staged rocket included a gas-discharge counter, which determined the intensity of primary cosmic-rays at high altitudes, and an onboard transmitter and power supplies. Ground-based equipment consisted of antennas, a receiver and oscillograph with a device for photographing the signals on film. The onboard equipment was installed in the nose cone of the rocket prior to launch.[6]

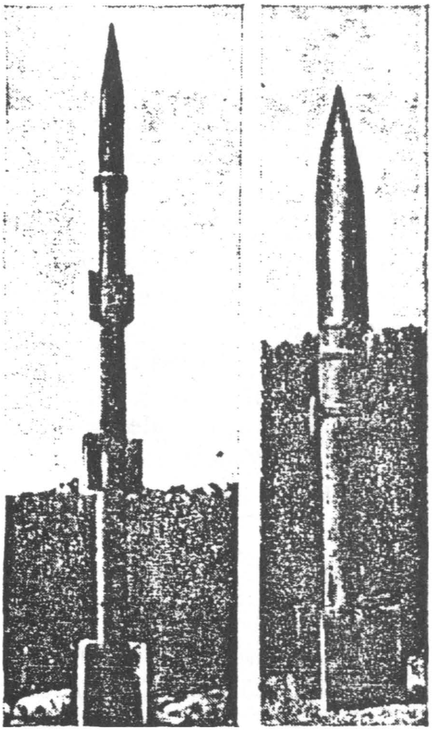

Figure 1 Stratosphere solid-propellant rocket of 1946. (To the right, the last stage of the rocket).

During June 1946, in the environs of Leningrad, engineers conducted three test firings of the solid-propellant stratosphere rocket of P. I. Ivanov with the equipment of FIAN; however, the rockets did not reach the required heights. Based on this test, and in view of the small load-carrying capacity of these rockets, the institute was forced to forego their further use. By this time work on liquid-propellant rockets had progressed, and these rockets promised greater possibilities, both in reaching the necessary heights and in lifting more diverse and heavier scientific equipment.

In the post-war years the USSR Academy of Sciences, which managed the hydrometeorological service of the USSR, and other organizations, paid enormous attention to the study of the upper air and cosmic rays. After 1947, the USSR Academy of Sciences, under S. I. Vavilov's chairmanship, which made a large contribution to these studies, regularly conducted conferences of a special committee that organized scientific upper-atmosphere research, including cosmic rays. In 1953, the Presidium of the USSR Academy of Sciences created a board for the coordination of works on upper-atmosphere research under the chairmanship of A. A. Blagonravov.

Back in the summer of 1947, at a conference sponsored by FIAN, S. P. Korolev was asked to examine the technical feasibility of installing instruments for conducting research on cosmic rays on liquid-propellant rockets. The first launching of such a rocket occurred on 2 November 1947. The experiments were prepared and the results analyzed by a group of colleagues in FIAN. The experiments measured the flow of charged particles beyond the limits of the atmosphere and investigated the processes in which the secondary component of cosmic rays formed during the interaction of particles of primary cosmic radiation with the atomic nuclei of different elements.

This assignment posed a number of special tasks for designers. Thus, for measuring the primary cosmic rays it was necessary to install the detectors away from the massive parts of the rockets, which could contribute to the appearance of secondary particles. The cavities in the stabilizers, which ensured a minimum deflection of the rocket in powered flight (less than 15%), proved to be the most suitable place for these detectors. Since during flight above the atmosphere the rocket could change its altitude in a uncontrolled manner, the detectors were arranged in a manner that was spherically symmetric. Fig. 2 shows the diagram of the layout of these instruments within the rocket.[7]

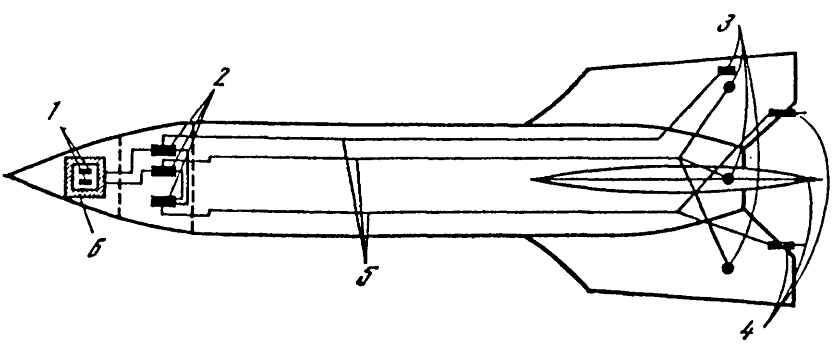

Figure 2 Arrangement of equipment for studying the cosmic rays on the research rocket of 1947. 1) instruments within an aluminum block; 2) electronic equipment of FIAN; 3) instruments in the tail fins; 4) antenna; 5) signal cables and electrical feed; 6) aluminum block.

To investigate the processes of the formation of secondary components of cosmic rays, a dense absorbent substance surrounded the detectors in a uniform layer, with a thickness of less than 30-40 g/cm^2 made of different materials (sand, lead and aluminum). The detectors, which consisted at first of single gas-discharge counters, and supplemented by ionization chambers, were placed within the cylindrical cavity in the nose cone of the rocket (Fig. 3). Here, the weight of the absorbent substance reached 50 g/cm^2. The missile instrument bay contained the electronic components for radio amplification and coding of the signals from the detectors, along with two transmitters that sent the coded signals to the Earth. The transmitters were connected by cables to the tail section of the rocket, where antennas were located on the leads of the stabilizers. The total weight of this equipment with the absorbent material reached 500 kg.

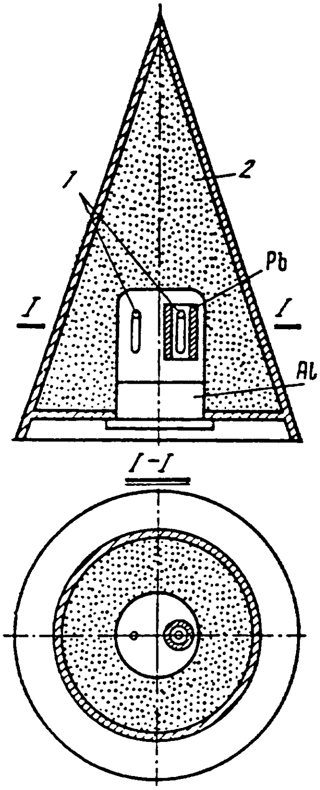

Figure 3 Arrangement of single counters in the nose of the research rocket of 1947. 1) counters; 2) sand.

This rocket, as all subsequent sounding rockets, was powered by liquid-propellant engines developed by the Gas Dynamics Laboratory--Experimental Design Bureau (GDL-OKB). The flight of the first rockets traveled along a ballistic trajectory that attained a maximum altitude of about 80 km. Although the duration of the flight at altitudes above 30 km was about 3 min, the data obtained made it possible for the first time to measure the effect of altitude on the number of cosmic-ray particles to heights of 50-80 km (Fig. 4), and to determine global cosmic-ray intensity (Fig. 5). The data about the secondary component of cosmic rays were also obtained.[7]

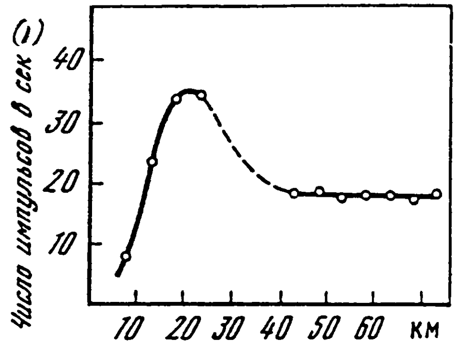

Figure 4 Altitude effect of cosmic-ray intensity according to data from the single counter. Key: (1) Number of pulses in s.

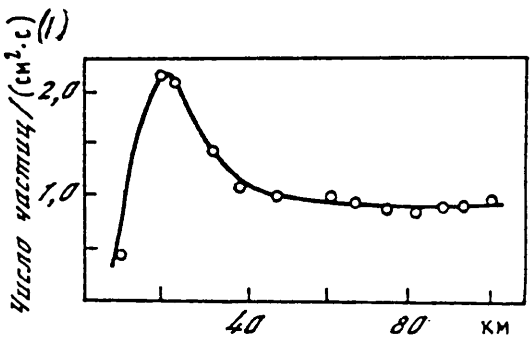

Figure 5 Dependence of global cosmic-ray intensity on altitude (according to data on several flights of research rockets in 1947-1951). Key: (1) Number of particles/(cm^2.s).

On the basis of first two experiments carried out in 1947, experimenters assumed that the electron-photon component was not primary, but originated in the process of absorbing initial particles. This was important for understanding the character of the interaction of charged particles with the atomic nuclei of the substance, and made it possible to derive conclusions about the existence of the mechanism of generation of a soft component unknown in earlier primary cosmic-ray research. As was established later, nuclear-stage processes, which lead to the formation of electric-nuclear showers, are such a mechanism.[8]

During October 1948, two more flights continued the experiments. In this case, for recording the secondary component of cosmic-rays, a system of three counters was utilized. The cavity, wherein the counters were located, was also surrounded on all sides by a layer of aluminum 40 g/cm^2. On the basis of data obtained during these flights, researchers determined the intensity of the electron-photon component formed in the aluminum filter (see Fig. 5).

Tests conducted in 1949 and 1951 measured the intensity of photons beyond the limits of the atmosphere at altitudes up to 100-115 km. The so-called "circular installation" consisted of a lead block containing a counter inside and surrounded outside by a group of counters connected in a parallel and linked with the internal counter. Preliminary experiments on sounding balloons equipped with the "circular installation" showed the presence of photons with an energy above 0.5 10^7 eV; moreover, the number of these photons proved to be approximately equal to the number of charged particles of the soft component. Experiments on the rockets made it possible to obtain data about the number of photons with an energy of more than 10^6 eV beyond the limits of the atmosphere, and to determine their dependence on height (Fig. 6).

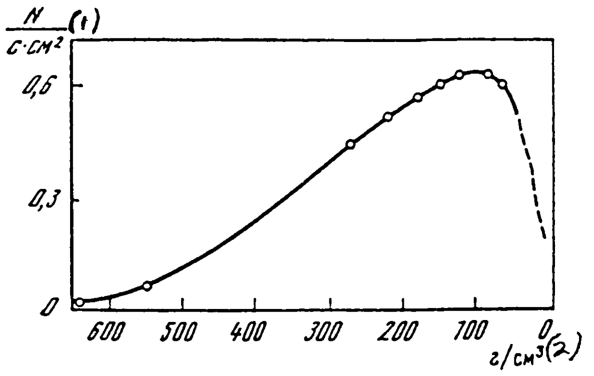

Figure 6 Altitude effect of number of photons, recorded by the "circular installation."
Key: (1) S cm^2 (2) g/cm^3

In 1951 measurements of cosmic rays with vertically launched rockets were carried out with the aid of ionization chambers. The chambers utilized in these experiments were of two types--integrating and pulse. Special recording of the ionizing current in the integrating chambers measured the average ionization, created by emission in the gas of the chamber. The amplitude of pulse of a single charged photon in transit through the pulse chamber appeared on the collecting anode in that chamber. A measuring circuit made it possible to record particles in the range of minimum ionization (multicharged particles). Ionization chambers of both types, surrounded by lead, were installed both in the stabilizers of the rocket and in its nosecone within the aluminum cavity. They measured the ionizing power of the particles of the primary cosmic radiation and obtained its high-altitude distribution (Fig. 7).

Comparison of the ionization and number of particles made it possible to determine the average ionizing power of particles of primary cosmic radiation and to obtain information about the charge composition of initial particles, to estimate the number of α-particles and nuclei z > 2 in the composition of primary cosmic radiation.

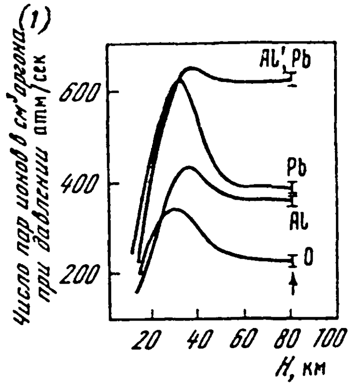

Figure 7 Dependence of ionization, measured by the ionization chambers, on altitude, with errors indicated taking into account averaging over altitude, H = 60-100 km.
Key: (1) The number of pairs of ions in cm^3 of argon at a pressure atm/s.

Beginning in 1948, colleagues of the Leningrad Radium Institute, under A. P. Zhadnov's management, began a series of rocket-borne experiments. They carried out analyses of the charge composition of cosmic rays with the aid of photoplates. They packed a unit of cassette plates into a steel cylinder placed near the wall of the missile body. After the rocket returned to Earth, they retrieved the container and plates. Researchers determined the charges of these particles and their intensity from the traces left by initial particles on the emulsion. Another group of specialists, under the management of N. N. Flerov of the USSR Academy of Sciences, conducted recordings of neutron fluxes. For these experiments, the neutron detectors with cadium retarders were installed in the rockets. The cycle of experiments in the study of cosmic rays with rockets was in essence completed in 1952.

As a result of these investigations, the number of charged particles beyond the limits of the atmosphere were measured, the altitude effect on the number of protons was obtained, and the number of α-particles and nuclei with $z > 2$ in the composition of primary cosmic radiation were evaluated. The study of secondary radiation, which appeared in the dense substance and which was detected with the aid of the counters and ionization chambers, showed that the electron-photon component was not primary, but originated from the interaction of the primary cosmic rays with the absorbent substance. The altitude effect of ionization was also obtained, and the average ionizing power of particles beyond the limits of the atmosphere was determined.[8]

The use of rockets for cosmic-ray research nevertheless disclosed a number of deficiencies. First, rockets launched at high altitudes functioned for an insignificant time (about 3 min), and this made it possible only to conduct research that did not require high statistical accuracy. Second, at the high altitudes the position [attitude] of the rocket in space changed. This related particularly to experiments in 1947-1949, when rocket launchings were conducted through a ballistic trajectory, and the position of the rocket in flight was completely unknown. To conduct the experiment it was thus necessary to satisfy the requirement of symmetry of installation for recording the cosmic rays in order to exclude dependence on the orientation of the rocket in space. Third, it was not easy to select a place for the instruments on the rocket sufficiently distant from its massive parts, since primary space particles in the denser substances create secondary particles.

Beginning with the rocket experiments in 1946, the Soviet Union also conducted numerous experiments on the measurement of cosmic rays using sounding balloons, substratospheric balloons, stratospheric balloons, and balloons launched from the station of the main administration of Hydrometeorological Service of the USSR, in a number of high-mountain stations, and on marine vessels, etc. Thus, in 1948 during the expedition aboard the ship "Vityaz" in the Indian Ocean, scientific gear was lofted into the stratosphere on sounding balloons.

A special service to study cosmic rays in the stratosphere was organized later, in 1957. After this date, sounding balloons for the study of cosmic rays were regularly (practically daily) released into the stratosphere from Murmansk, Leningrad, Moscow, Simferopol', Alma Ata, and in the Antarctic. Still earlier, special high-mountain stations for cosmic-ray research were established in the Caucasus, Tien Shan, and Pamirs. At present, in different parts of the terrestrial globe, there is a wide network of stations which continuously record cosmic rays.

The experiments on rockets made significant contributions to the study of cosmic rays outside boundary of the atmosphere, and prepared the scientific-technical base for continuing investigations of cosmic radiation with satellites and automatic interplanetary stations, not only beyond the limits of the atmosphere, but also in the magnetosphere of the Earth.

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