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Chapter 13

SCIENTIFIC INVESTIGATIONS CARRIED OUT BY THE FIRST SOVIET SATELLITES AND THEIR RESULTS*

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Flights of the first Soviet artificial Earth satellites marked the beginning of direct research of the properties of near-Earth outer space and of biomedical experiments that demonstrated the possibility of organisms living for prolonged periods in zero gravity. This report addresses the first of these research issues.

Studies of the upper atmosphere and near-Earth space were conducted on the basis of indirect data until the moment when the first Soviet satellites were launched. The atmosphere and ionosphere of the Earth terminate at altitudes of approximately 1,000 km. Solar plasma is located at higher altitudes. Two hypotheses attempted to explain the nature of solar plasma. According to one, the sun's external atmosphere exists in hydrostatic equilibrium, disrupted from time to time by the ejection of substances during solar flares. The quasi-stationary jets limited in space were observed against a background of the fixed atmosphere--the corpuscular fluxes, which escape from the active regions. The second hypothesis--positing the continuous outflow of solar wind from the entire surface of the sun--arose not long before the beginning of the space age in connection with the interpretation of the eleven-year course of cosmic-ray intensity. But the nature of the interaction of solar plasma with the magnetic field of the Earth remained unclear. It was assumed that the amplification of plasma flows led to the reduction of the geomagnetic field, and that the flow of plasma burst open in the high-latitude regions of the Earth and caused the aurorae polaris.

In spite of considerable uncertainty, these hypotheses made it possible to plan an effective program of measurements for the first Soviet satellites. The program included: a) cosmic-ray research with the aid of gas-discharge and luminescent counters; b) the measurement of the parameters of the ionic and electronic components of the ionosphere; c) the search for energetic particles that cause aurorae polaris; d) the manometric and mass-spectroscopic analyses of the density and composition of the neutral atmosphere; e) the study of the properties of the ionosphere with the aid of analysis of the propagation of radio signals from the satellite. The

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study program using artificial satellites was closely related to the wider circle of questions studied during the International Geophysical Year [IGY]. The number of experiments conducted and results obtained grew sharply from one satellite to the next, and the results obtained from the third Soviet Earth satellite made possible a cardinal review of early hypotheses about near-Earth outer space, and the shaping of contemporary theory.

The discovery of external radiation belts and a determination of their composition was the principal result of experiments on the first Soviet satellite. As is known, the first American Earth satellite discovered in the equatorial area a sharp increase in the intensity of energetic charged particles with increasing height. The third Soviet satellite confirmed this fact, using a combination of gas-discharge and luminescent counters to study high-energy particles. It proved to be, however, that analogous increases are observed not only in latitude, but also about 60 degrees north and south latitude. In this case, the intensities both in the low-latitude and in the high-latitude areas exceeded the flow of cosmic rays by many orders.

From comparing these data, scientists determined that a considerable number of protons with energies of tens of MeV collect in the internal (low-latitude) zone. Such protons are absent in the external (high-latitude) zone and electrons are the basic component there. Figure 1* shows the data of the gas-discharge and luminescent counters from the third Soviet satellite, which testify to the presence of an external radiation belt.

Drawing on an interpretation of the data about radiation belts, the theory of magnetic traps was developed in connection with the problem of thermonuclear fusion. It followed from this theory that the form of the belt is determined by the course of the lines of force of the geomagnetic field, and that on each line of force the intensity reaches a maximum near the equatorial plane. This was confirmed during the flight of the first Soviet space probes to the Moon. During these same flights, using completely difference equipment--ion traps--scientists established the upper limit of the intensity of electrons in the outer belt. This evaluation made it possible to conclude, in combination with other data, that the medium energy of the electrons in the outer belt is hundreds of keV and that there is a considerable quantity of relativistic electrons with energies of more than 1 MeV. The electron streams of this energy out of the radiation belts have extremely low intensity. However, energies of the electrons, which cause aurorae polaris, are one-to-two orders lower. Thus, it became clear that in the radiation belts a powerful accelerating mechanism generates electrons with energies up to several MeV.

As far as the nature of the high-energy protons of the inner zone is concerned, however, it turned out that cosmic rays are their source. Interacting with the nuclei in the atmosphere, cosmic rays generated neutrons with energies up to hundreds and thousands of MeV. Part of these neutrons decompose within the limits of the geomagnetic field, and their decay products (protons and electrons) are seized.

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* **Editor's Note**: Illustrations were not submitted with this paper.

Data from the third Soviet satellite, the first moon probes, and the first American satellites showed that between the inner and outer belts there is a clearance in which the flow of energetic particles is very low. Equipment on the third Soviet satellite, intended to search for particles of the aurorae polaris (electrons with energies of 10 keV) recorded in the clearance region considerable flows of the particles seized by the geomagnetic field (the capture indicated considerable modulation of flow during the rotation of the satellite around its axis). It was subsequently learned that in this case protons with energies of approximately l MeV were recorded which did not penetrate through the protection of the other detectors. Thus, it turned out that a large quantity of protons with energies in the tens of keV--several MeV--is contained in the radiation belts.

In 1964-1965, with the aid of the "Electron" series of satellites, spatial distributions, energy spectra, and time variations in protons and electrons in the Earth's radiation belts were studied in detail. By this time the theory of the shaping of these belts was developed. It turned out that the diffusion of particles across the lines of force of the magnetic field under the action of probability electric fields caused the acceleration. Falling into the stronger magnetic field, particles are accelerated according to the principle of the operation of betatron. The radiation belts of Jupiter were discovered in recent years. Figure 2 gives the evolution of our understanding of the Earth's radiation belts.

As mentioned previously, the first Soviet satellite investigated the characteristics of the ionosphere. Electrostatic traps were used for this, which made it possible to measure the electron streams and ions with energies from fractions of eV to hundreds of eV. However, first results showed that the ionosphere of the Earth by no means terminates at altitudes of approximately 1,000 km, and that up to the apogee of the satellite (1,500 km) electron concentration remained very high. These findings served as the base for installing traps on lunar probes and other automatic interplanetary space probes.

The results eventually obtained proved to be even more unexpected. It was learned that the concentration of cold plasma (with the temperature of approximately 1 eV) remains very high in the region, limited by lines of force with a maximum distance from the center of the Earth of approximately 30,000 km (4-5 Earth radii), and then falls sharply. At even greater distances (60-70 thousand km from the center of the Earth) on the daylight side, a sharply limited layer of plasma with the medium energies of protons in the hundreds of keV appears. Furthermore, the previously forecast theoretical flow of solar plasma, or solar wind, was observed. The density of the flow, however, proved to be considerably below what the theory predicted. The data relating to the change in properties of the plasma correlated well with changes in the nature of the magnetic field.

These results became the basis of a concept of the magnetosphere encasing the Earth, whose properties are determined by the interaction of the solar wind and the geomagnetic field. Figure 3 is a diagram of the magnetosphere according to contemporary theory. Solar wind is carried past the Earth at a velocity approximately of an order that exceeds the speed of sound and hydromagnetic waves in the wind. In this case, as during any supersonic flow, a shock wave is formed behind a front in which the plasma is turbulent, and part of the kinetic energy converts into the energy of thermal particle motion.

The boundary of the region, the transition region between the shock wave and the magnetopause, is localized in the magnetic field of the Earth. This transition region was recorded for the first time with the aid of ion traps at distances of 60-70 thousand km from the center of the Earth. On the night side, the magnetopause forms an extended cylindrical cavity, observed up to the distances of thousands of Earth radii. In the middle of the night the magnetosphere is arranged in a thin plasma layer, which divides regions with antiparallel magnetic fields. The internal boundary of the plasma layer is located at distances 7-10 Earth radii from the center of the Earth.

The lines of force of the geomagnetic field, which correspond to the plasma layer, are projected toward the surface of the Earth along circular regions in the northern and southern hemispheres. In these regions (auroral ovals), the most powerful magnetic perturbation, aurorae polaris, and ionosphere disturbances are concentrated. Closer to Earth, the lines of force form a magnetic trap, in which the Earth's radiation belts and a dense ionosphere (plasmasphere) are located, as discussed above.

The structure examined can change substantially depending on the properties of the solar wind (in particular, its magnetic field); however, the structural elements enumerated above are always retained, changed only in the sizes or intensity of particle fluxes.

The concept of a magnetosphere made it possible to explain a series of geophysical phenomena. For example, the series of the characteristic types of electromagnetic disturbances with frequencies from hundredths of hertz to tens of kilohertz, observed by ground stations, appears due to the plasma instabilities of different elements of the magnetosphere and the radiation belts. In recent years we also learned that the motions of plasma in the magnetosphere generate powerful currents along the lines of force, which are closed in the ionosphere. These currents, in turn, generate electrons which excite aurorae polaris.

With each year the study of the magnetosphere-ionosphere continues, bringing new questions to be solved. Study of the magnetosphere of Jupiter allows many properties of magnetospheres to be simulated in the laboratory. It becomes ever more obvious that the plasma processes, initially revealed and studied in near-Earth space, are universal and characterize an interaction of space plasma with other celestial objects that have proper magnetic fields.

Magnetospheric studies are extremely important from the point of view of mastering space. The problems of radiation safety and space materials science can be successfully solved only on the basis of a clear understanding of the structure and dynamics of near-Earth plasma. The same conclusion also relates to the many problems connected with disturbances of radio communication and magnetic perturbation.

Noting the twentieth anniversary of the launch of the first Soviet satellite, we can say with pride that the first satellites and space probes established the basis for one of the important scientific achievements of the 20th century, and changed our fundamental understanding of geophysics and astrophysics. Finally, one cannot fail to note that another most important result of the scientific investigations of the first Soviet satellite was the development of wide international collaboration among scientists of the world in space research--a collaboration today that sharply raises the effectiveness of our investigations and draws together peoples of different countries.