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VARIATIONS OF COSMIC RAYS AND PROBLEMS OF SOLAR-TERRESTRIAL PHYSICS

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SUMMARY

The problems of solar-terrestrial physics are discussed mainly with respect to cosmic ray variations. Particular attention is given to solar cosmic rays of which various generation mechanisms are discussed. Considered as very valuable are also the data on magnetic fields in solar wind, derived from those on cosmic rays, and on electromagnetic processes at great distances from the ecliptic plane. The results of study of the 11-year cycle of cosmic ray variations were also instrumental in collecting data on solar wind at distances in tens astronomical units, mainly during plasma flows in periods of high solar activity. Considerable light has also been thrown on electromagnetic and nuclear processes taking place on the Sun. Finally, radiation hazards in the interplanetary and galactic space, for manned flights are also discussed especially with emphassis in the possibility of finding the space-time distribution of the radiation dose.

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The influence of the Sun on processes taking place on Earth and its vicinity as well as on interplanetary space is produced by two types of solar radiation: electromagnetic and corpuscular. Although the electromagnetic radiation is energetically seven times higher than the corpuslar radiation ($4 \cdot 10^{34}$ and $4 \cdot 10^{26}$ erg/sec), there are some space regions, where the latter is a decisive factor. First and foremost these are the interplanetary space and the Earth's magnetosphere, practically transparent for electromagnetic radiation, as well as the lower ionospheric layers, not reduced by the ionizing ultraviolet radiation, but substantially influenced by the high-energy corpuscular radiation.

Related to corpuscular radiation are also the solar cosmic rays (protons, α-particles and other much heavier nuclei, electrons, neutrino, γ-quanta and neutrons in broad energy band ranging from some tens of kev up to some tens of Gev), as well as the plasma flux with mean kinetic energy of few kev, that is, solar wind, perturbed by recurrent corpuscular fluxes and shock waves from powerful solar flares. The investigation of cosmic ray variations by means of ground methods (neutron monitors at sea and mountain levels, mesonic telescopes on the Earth's surface and at various subterranean depths, neutrino undergound installations, measurements of cosmic rays on balloons), and also with the aid of AES and cosmic rockets, give an important and manifold information about solar cosmic rays and solar wind.

To obtain a clear information, the data from the ground observations, eliminate first of all the distorted influence of meteorological effects (with the help of a standard method, based on the theory worked out in detail some 10 years ago) and detect variations of primary cosmic rays beyond the limit of Earth's magnetosphere (by means of coupling coefficient method and computery data on asymptotic cones of particle reception in the geomagnetic field).

Information on solar cosmic rays appears to be direct and therefore absolutely reliable. What does the study of these rays offer to the problems of solar-terrestrial physics?

At the present time we dispose of a rather complete information on their energetic spectra and chemical composition according to basic measurements on Earth and in its vicinity. Investigation of solar cosmic rays propagation in interplanetary space according to measurement data on the variation with time of their anisotropy and intensity made it possible to evaluate the transport path for scattering as a function of particles' energy and distance from the Sun.

In order to explain the obtained information it was necessary to postulate the existence of regular spiral structure of the regular part of the interplanetary magnetic field and of a wide spectrum of magnetic heterogeneities in the solar wind. Subsequently this hypothesis was successfuly confirmed by a direct measurements in the outer space. It was found that before the Earth's orbit, the field is much more regular (transport path for scattering near 1 astronomical unit), but at distances of several astronomical units, the field already becomes to a greater degree irregular (path for scattering diminished almost by an order). As it was found out, the energy spectrum of solar cosmic rays changes substantially from case to case, but, on the whole, it is always much more softer than the spectrum of galactic cosmic rays. For $Z \geqslant 2$ the chemical composition is closer to the composition of solar atmosphere, but the relative content in hydrogen nuclei, varies within the range of two orders. According to measurements taken on satellites, it was possible to establish several cases of generation, of heavy nuclei only (during a period of absence of powerful solar flares on the Sun).

The whole period of solar cosmic rays advent on Earth may be broken down into two phases: the anisotropic and isotropic. The anisotropic phase is expressed by the solution of a kinetic equation applicable for the description of propagation in the initial period of a chromospheric flare (inside the Earth's orbit, where the transport path for scattering is comparable with the radius of Earth's orbit). The isotropic phase is described by the anisotropic diffusion equation. It characterizes a period, when solar cosmic rays depart beyond the limits of the Earth's orbit. The propagation conditions distort their spectrum and chemical composition. However, the investigation of anisotropy and temporal course of intensity of these rays allows us to determine the propagation parameters for particles of different energy in the interplanetary space, which in its turn provide the possibility of finding their real energy spectrum and chemical composition at the source, where generation processes take place.

As to the generation mechanisms one should apparently speak of three of their types:

1) acceleration by Fermi mechanism of first order, when generation takes place in lower layers of the chromosphere and when thermonuclear reactions constitute the injector (cosmic ray flares rich in protons);

2) acceleration by mechanism of magnetic dissipation during the "slamming" of oppositely directed magnetic fields, when acceleration of all the particles takes place in the neutral line region of the upper chromosphere (cosmic ray flares during powerful chromospheric eruptions with chemical composition of generated particles, close to that of solar atmosphere);

3) acceleration by comparatively weak processes of solar activity in the lower corona, when its constant is small (accelerated are mostly the not fully ionized heavy atoms from the high-energy tail of Maxwellian distribution, which gradually lose completely the electronic shell as the energy increases).

Of exceptioannly great value is the information on magnetic fields in the solar wind, derived from the data on cosmic rays. It is enough to say that the first evaluations of the strength and structure of magnetic fields in the quiet (several gammas[1]) and perturbed (several tens of gammas) wind, were made from the analysis of modulation effects of galactic cosmic rays, many years prior to measurements in outer space. It is necessary to stress, that if the direct observations of solar wind, encompass

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[1] 1 gamma = 10^{-5} gs.

a rather small volume of interplanetary space, especially between the Mars and Venus orbits, the investigations of various type of cosmic ray variations allow us to obtain data on solar wind properties at more substantial distances from the Sun, i.e. of several tens and hundreds astronomical units. Besides, it is possible to obtain with the aid of cosmic rays the information on electromagnetic processes at great distances from the ecliptic plane (by means of study of anisotropic cosmic rays and annual variations, while up until now all the direct observations were carried out only in the ecliptic plane.

Thus, the investigation of 11-year cosmic rays' variations, enabled us to collect data on solar wind at distances in tens astronomical units. It has been established, that in the period of solar activity maximum the flux of solar plasma reaches the distance of about 100 astronomical units. In this volume the average wind velocity is around 300 km/sec. Between the boundary of solar wind and of the galactic magnetic field, there is a turbulent layer of several tens astronomical units thickness. Diffusion of cosmic rays and acceleration of low-energy particles takes place in that layer. The completed evaluation of modulation parameter allowed us to restore the energy spectrum and the chemical composition of galactic cosmic rays beyond the solar wind boundary. This led in its turn to the conclusion that an important role in solar wind limitation must be ascribed to the pressure of the magnetic field, as well as that of the low-energy galactic cosmic rays, reflected and unadmissable by solar wind into the solar system.

Analysis of annual variations and anisotropy of cosmic rays permitted to establish that there are in interplanetary space an average of about two regions of decreased cosmic ray density on both sides from helioequator corresponding to the spot zones of solar activity. Found also was the longitudinal asymmetry in the distribution in the density of cosmic rays' manifest in the form of cyclic variations with a period close to that of Sun's rotation. It becomes possible to reveal by the cyclical variations of cosmic rays' anisotropy, a sectorial structure of interplanetary magnetic field (it dates back also to the time when direct measurements of magnetic field in the outer space did not exist as yet). Finally, the investigation of microvariations with short periods provides information about the thin, filamentary structure of the interplanetary magnetic field.

Important data on perturbations in the solar wind may be obtained by means of studying the Forbush-effects that is, of sharp decreases of cosmic ray intensity during the periods of magnetic storms (fundamentally with sudden commencement). By these effects, the width of the shock wave region and the magnetic field in it, intensified up to several tens of gammas, were estimated long before the time of direct measurements in outer space.

It was discovered, that prior to the start of magnetic storms (roughly 10 to 12 hours ahead) there occurs a slight increase of cosmic ray intensity bearing a sharp anisotropic character. These are the so called forewarners of magnetic storms in cosmic rays. They are conditioned by the reflection of cosmic particles (with corresponding energy increase) in the region of the enhanced magnetic field, moving in the direction from the Sun at the speed of $\sim$ 1000 km/sec.

Bearing a direct relation to the problems of solar-terrestrial physics is another very important phase of investigation of cosmic ray variations, namely, the research of radiation hazards during manned flihgts in the interplanetary and galactic space. The hazards are determined at rather small distance from the Sun during perturbed periods mainly by solar cosmic rays, their space-temporal distribution, their energy spectra and their charge composition. However, in quiet periods, as well as in perturbed ones, but at much larges distances from the Sun, the radiation hazards are determined mainly by galactic cosmic rays. The investigation of solar and galactic cosmic rays' distribution in the interplanetary space (by means of anisotropic diffusion model with the transfer at the expense of radial divergence of solar wind and bearing in mind the variations of energetic particles) allows us to restore the pattern by observation data in the limited space volume of space-energetic distribution of cosmic rays inside the solar system, and consequently, to find the space-time distribution of the radiation dose.

The investigation of cosmic rays offers interest for a series of subdivisions of solar-terrestrial physics studying the Earth's immediate vicinity. First of all it pertains to the investigation of cosmic rays' influence on the lower ionosphere and creation of the so called layer of cosmic rays (CR-layer). A sharp intensification of this layer at high latitudes during the periods of solar flares leads to absorption increase and complete cessation of radio-communication on short waves. Further, one should recall the data derived as a result of sounding by cosmic rays of the magnetosphere structure and of "extra-ionospheric" current systems. In particular the extension of the magnetosphere into the night side, just as the parameters of the current system, inducing the main phase of a magnetic storm that were unambiguously evaluated using ground magnetic data, were first established with the aid of cosmic rays (several years prior to direct measurements on satellites). Finally, the meteorological effects of cosmic rays by ground and underground observations, allowing a continuous air temperature measurement in the stratosphere, have a great significance. In particular daily variations could be measured this way (free of errors linked with radiation heating of sensors during direct measurements with the aid of meteosondes) and the same goes for the 27-day temperature variations.

Thus, the investigation of cosmic rays' variations, yields important information on the problems of solar-terrestrial physics, and on processes of the Earth's environment and in the interplanetary space (up to the greatest distances towards which the solar wind extends). At the same time cosmic rays enable us to obtain data on electromagnetic and nuclear processes taking place directly in the Sun, and accompanied by fast particles' generation, and even on the processes in solar interior connected with thermonuclear reactions producing the neutrino.

It should be noted that with the availability of computer processing of all the complex data of the universal network of cosmic ray stations, according to an especially developed program, it is possible in principle, to obtain very quickly a current information and at the same time to release certain forecasts on various above mentioned questions. However, this demands the conduction of a big, scientifically investigated and organized work (let us note, in particular, that some successful attempts were already made in obtaining time-continuous charts of cosmic ray distribution in the interplanetary space).

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