

Cosmic Ray investigation in stratosphere and space: some results from instruments on Russian satellites and balloons.

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Abstract. Selected activities with the aim to describe cosmic ray fluxes and to contribute the understanding of the mechanisms behind, over long time period with using the space research tools in the former USSR and in Russia, are reviewed, and some of the results obtained are listed. Selection is connected with the institutes where the authors are working. Thus it has to be assumed as a partial review on the wide topic.

1. Some milestones until mid of the last century.

Investigation of cosmic rays began in 1900-1901, i.e. more than 100 years ago. First ten years the reserchers did not know they study cosmic rays. All began from the time of measurements of conductivity of various gases including the air, when there was observed some "residual" ionization, i.e. a weak "dark current" observed even without ionising sources. First publications of those experiments relate to period 1900-1901 [1]. One of the first researchers of "dark current" was Ch. Wilson, well known as the inventor of Wilson chamber (1912), which was widely used for studies of various types of radiation, including also cosmic rays. Later, in 1927, Ch. Wilson for this finding was awarded the Nobel Prize. Due to those experiments it became clear that at sea level always exists some not large but strongly penetrating radiation (that was observed also in strongly screened chambers). At the beginning it was thought that the radiation is emanating from the soil, similarly to Earth's radioactivity, and that is why it must be declining above the Earth's surface. However, the radiation was declining just up to the altitude about one km while above this level its intensity was increasing. The fact that radiation intensity increases with altitude was known in 1912 after experiments of Austrian physicists V. Hess [2], who measured radiation by ionization chamber up to more than 5 km. V. Hess called it "altitude radiation". This name was used until 1925. The nature of that radiation was not clarified for long time. There were proposed several hypotheses of its origin (e.g. it is originated in the upper layers of the atmosphere due to atmospheric electricity). Finally, the extraterrestrial origin of "altitude radiation" was proved by R.A. Millikan (USA) in 1923-1924, who introduced the term "cosmic rays" [3]. At that time R.A. Millikan was already awarded the Nobel Prize (in 1923 he was awarded the Nobel Prize for measurement of the charge of electron). Cosmic rays remained over rather long time period the "mystery effect". This is argued by the fact that Nobel Prize for its discovery was awarded to V. Hess only in 1932, i.e. 20 years after his experiments.

In this short review there are discussed few selected milestones in the cosmic ray research, to which authors of the paper among many other scientists of the former USSR and Czechoslovakia contributed.

In 1926 physicists in Leningrad L.M. Mysovskij and L. Tuwim found that intensity of cosmic rays is changing with the pressure of air. They discovered barometric effect of cosmic rays which is well known at present [4]. D.V. Skobeltsyn in 1927 during the works with the Wilson chamber put into the magnetic field, found that cosmic rays at the sea level are electrically charged particles of very high energy [5].

Scientists in the former USSR began to persue intensively with cosmic ray research , starting from 1920-es. Let us mention the works of several groups in Leningrad, Kharkov and Moscow. The basic successes of the groups are results of L.N. Mysovskij and colleagues, D.V. Skobeltsyn and of the group of S.N. Vernov. The work in former USSR was aligned with the same scientific directions as in the other countries of the world, however with some delay due to the tensioned international and domestic situation as well as with the complicated exchange of information during that times. Until the works of L.M. Mysovskij the predominant opinion was that the altitude radiation is close to the radiation of radioactive nuclei. L.V. Mysovskij and his colleagues accomplished in 1925 at the Lake Onega the measurements of absorption coefficient of altitude radiation in the water [6], which appeared to be by one order lower than that for gamma rays of Ra, which indicated that the altitude radiation possesses much higher penetration ability than gamma rays emitted by radioactive nuclei. These works along with the experiments by R.A. Millikan and G.H. Cameron [7] on the absorption of altitude radiation in the water at various levels above the sea one led to the conclusion that the altitude radiation is coming to the ground from above and that it has very high penetration ability.

In 1927 D.V. Skobeltsyn found in Wilson chamber inserted in the magnetic field not numerous tracks of relativistic particles not bent by the magnetic field. He determined the energy of particles and came to the conclusion that these are particles of altitude radiation [5], which according to R.A. Millikan obtained the name “cosmic rays” [8].

In 1929 D.V. Skobeltsyn published his paper, where he showed that cosmic rays (CR) may create several particles, the showers of cosmic rays [9]. After several years with help of Wilson chamber, controlled by the system of coincidence from the detectors surrounding the chamber, various researchers obtained the photos of the cosmic ray showers with high number of particles (see e.g. [10]). The importance of discovery of cosmic ray showers is in the awareness of the fact of the processes in cosmic rays which do not exist in the interactions of particles with lower energies. Cosmic rays allowed to get in deeper into elementary particle structure and initiated development of acceleration technique.

Third group of cosmic ray researchers established and lead by S.N. Vernov. Especially that group, in the following period, carried out most exhaustive and miscellaneous cosmic ray research in USSR: on the ground, at mountain altitudes, in the stratosphere, and subsequently on satellites and other space vehicles. These investigations are shortly described below.

We should like to say few words about the leader of the works of the group – Sergey Nikolaevich Vernov (SNV, 1916-1982), who started his cosmic ray studies very young, at the age just above 20. SNV was a student of D.V. Skobeltsyn. He was familiar with the works and results of physicists in Leningrad, and he has seen how distinguished scientists

deal with cosmic ray physics, and thus his choice of cosmic ray physics was rightful. In the first half of 1930-es they were known only the hypotheses about the primary cosmic rays (particles accessing the Earth's atmosphere from outer space). Thus, for understanding the nature of cosmic rays, it was necessary to conduct the experiments closer to its source, near the boundary of the atmosphere. That is why SNV decided to carry out the measurements in the upper stratosphere. However, on this way there was a serious difficulty because at that time the experimenters had no possibility to arise with the instrument to high altitude. That is why the experimental devices with automatic recording system have been developed and measurements provided without the people.

Research of stratosphere was provided also by other researchers and the flights of stratostats began. Near Moscow on September 30, 1933 the stratostat with the name "SSSR-1" was launched and reached 19 km. Stratonauts with help of electrometers of Hess and Kohlhoester measured cosmic ray intensity and confirmed the data about cosmic (extraterrestrial) origin of the rays and about the role of atmosphere in their screening. One of the flights of stratostats finished by a tragedy – three stratonauts died. S.N. Vernov found a solution of that problem – to translate the results of measurements by radio waves. He utilized the experience of Leningrad's professor P.A. Molchanov, who in 1930 for the first time in the world constructed the radiosonde translating the meteorological information by radio. SNV jointly with P.A. Molchanov and L.V. Mysovsky in 1934 is developing the instrument and for the first time cosmic ray measurements in the atmosphere are transmitted to Earth by radio. In the Report of Academy of Sciences of USSR for the year 1934 there is written that "experience with detection of cosmic rays was provided by the PhD student of Radio Institute S.N. Vernov". First automatically adjusting flight of radiosonde took place on April 1, 1935 [11]. In the same year S.N. Vernov defended his PhD thesis on subject "Investigation of cosmic rays in the stratosphere by means of radiosondes". Academician S.I. Vavilov liked the thesis by S.N. Vernov and he invited him to doctoral study to FIAN (Physical Institute of Academy of Sciences) for continuation his research of cosmic rays. This was the termination of the research by S.N. Vernov in Leningrad. Since 1935 he moved to Moscow where he worked continuously until his death.

Improving the method of measurement of cosmic rays on the stratospheric balloons, S.N. Vernov conducted successful study of the latitudinal effect of cosmic rays in the stratosphere in 1936-1938 at several sites: Leningrad, Yerevan and in the region of equator [12]. For that purpose S.N. Vernov organized and lead the nautical expedition. Tanker named "Segro Ordzhonikidze" sailed from Odessa to Vladivostok and backward and in Indian ocean from the board there were flown the stratospheric balloons. Experiments in stratosphere have shown that the flux of cosmic rays near equator is by ~4 times lower than at high latitudes. It was the indication that magnetic field of Earth declines cosmic rays and, consequently cosmic rays consists of charged particles. Similar experiments were done slightly earlier by R.A. Millikan [13], which definitely proved that cosmic rays are not neutral particles as e.g. gamma quanta. However, for the determination of cosmic ray composition still remained several years.

In that period the group of S.N. Vernov was concerned with the research of cosmic rays in the upper layers of atmosphere by means of instruments, flown on radiosondes. In Figure 1 the moment of launch of the instrument on the garland of the balloons which

required the quiet conditions of the atmosphere and the known expertness to get away from the effect of pendulum and of impact with the neighbor structures.

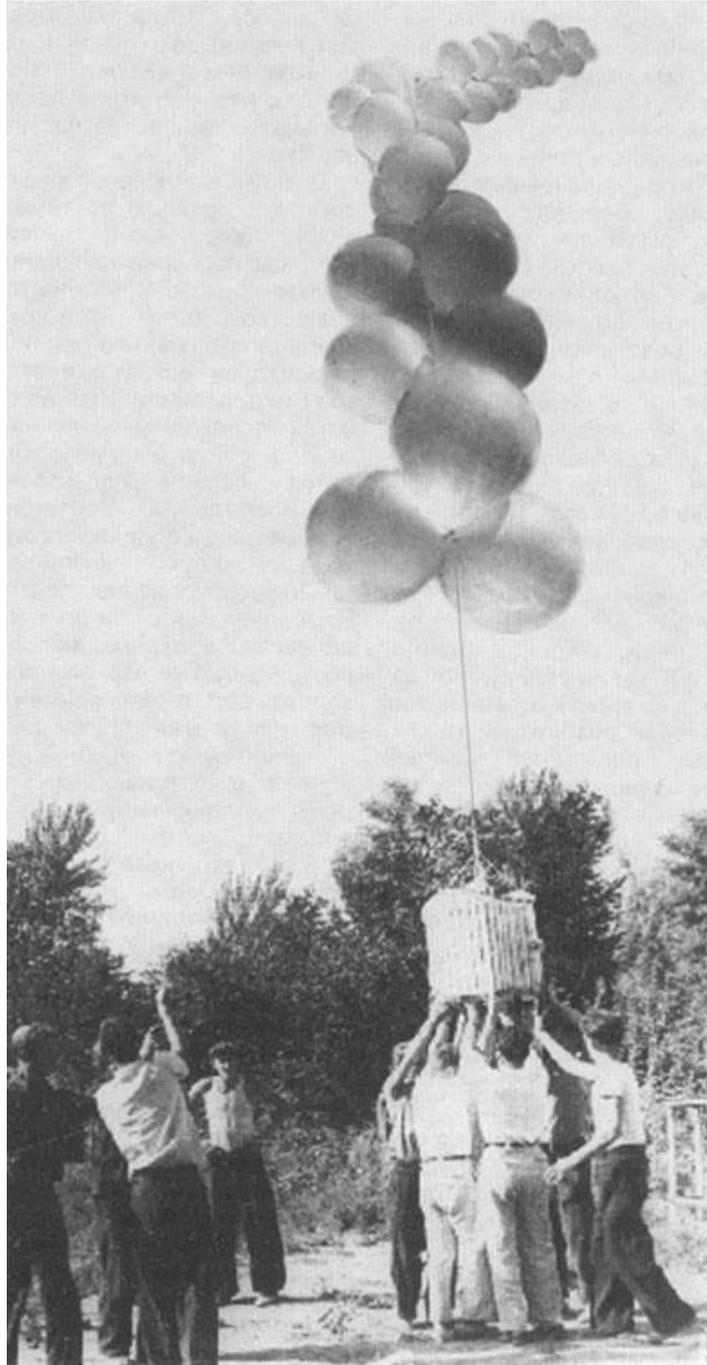


Fig. 1. Moment of launching the instrument for cosmic ray research on the garland of the balloons.

The way in cosmic ray research by SNV was spurred. There was only few experimental facts and they were frequently contradictory, so that his viewpoints were changing in accord with the new facts. First he supposed that cosmic ray particles have small mass – light particles as the electrons have. Later it appeared that the particles in passage through

materials behave not as electrons, their “multiplication” are not in accord with quantum theory assuming even relativistic effects. SNV was moving towards the idea that primary cosmic rays are heavier, i.e. protons, and that proving it requires to determine the charge of particles. This was done by using geomagnetic field as a giant magnetic analyzer sensitive to the charged of analyzed particles. For that the instrument was flown into stratosphere, where the effect is more pronounced, from board of the research vessel “Vityaz”. First flight confirmed the assumption about positive electric charge of primary particles, which by augmentation during passage of atmosphere, produce secondary particles, electrons [14].

Presently the knowledge about primary cosmic rays is almost complete. We know that primaries consist of nuclei of all elements of Mendeleev table, basically protons and alpha particles, however there are apparent also nuclei and oxygen and iron, and very rarely also uranium nuclei. We know that cosmic rays arrive to vicinity of Earth from distant space and that they bring negligible flux of energy (by 10^6 times lower than that of solar light). We know that the individual particles carry the enormous energy (by 10^3 times higher than collider in CERN). We know that these particles with enormous energy collide with the nuclei of the atmosphere producing thus the extensive air showers, not the black holes. Cosmic rays interacted with the Earth millions of years and did not crashed anybody.

The regular detection of cosmic rays in the stratosphere started in former USSR in 1955 and it is run regularly till today. This allowed to obtain continuous long time series of cosmic ray data, to study the mechanisms of primary cosmic ray interactions with the nuclei of atmosphere, to find that also the Sun generates cosmic rays with somewhat lower energies than primary ones. Year 1957 is the starting year of space era. SNV immediately used the new technical tool for cosmic ray studies. The takeoff of those investigations is amazing, the scientific group led by SNV accomplished more than 300 experiments onboard of various cosmic apparatuses. The weight of the developed scientific devices measuring in space in dependence of the tasks and possibilities, ranged from 500 g to 10 tons. Some of these experiments were not repeated, and in the paper they are mentioned shortly.

For the investigation of particles with very high energy, SNV created in Moscow State University a huge (according to that time) equipment consisting of hundreds of units over the territory of University campus, each of them with the complex device detecting thus each secondary particle produced in the Earth’s atmosphere by a primary particle. Such equipments have been established later in Yakutsk (in Moscow there was not sufficient area) and in Samarkand (better atmospheric conditions). In this manner, the whole scientific life of SNV has been divided into three competitive directions: cosmic ray research in the atmosphere of Earth, in space, and on the ground. Due to brilliant experience and large effort of SNV all three directions were developed.

Below the experiments in the stratosphere and in space will be shortly described. The research of extensive atmospheric showers is not touched since the authors of the paper did not participate in that scientific direction.

2. Cosmic ray research on the artificial satellites of Earth, on other spacecrafts and in the upper atmosphere.

2.1. Galactic cosmic rays.

Preparation of experiments for the satellites began in USSR in 1956. At the meeting of Academy of Sciences of USSR there was formulated the task for the leading specialists on physics of upper atmosphere, magnetic field, ionosphere and cosmic rays to provide suggestions – projects of the experiments on artificial satellites of Earth. Academician D. Skobeltsyn participating at the meeting authorised S.N. Vernov to conduct these activities. Along with one of the authors of the paper (Yu.I. Logachev) SNV step up to design and development of the device for detection of cosmic ray particles. Trajectories of the first satellites were on the altitudes 300-1500 km. At these altitudes, along with the cosmic ray particles, there has been particles trapped in geomagnetic field (radiation belts of Earth). However, during the development of the measurement device for the first artificial satellites of Earth, this was not known, and the apparatus was targeted only to cosmic ray research. In Figure 2 there is principal scheme of the detectors and of the electronics for the instruments installed in the second Soviet satellite flown onto the orbit on November 3, 1957. The deadlines were tight, the technology was new, and naturally the suggestions of the authors of the construction of the instrument have been limited by very simple understanding: to utilize as detectors the gas discharge counters and semiconductor electronics. S.N. Vernov supported completely the suggestions. Let us remark that presently there are working in space rather sophisticated complex detector systems, utilizing practically all recent methods of particle detection: scintillation and semiconductor counters, magnetic spectrometers, track detectors and their combinations. The elements of orbit of the second Soviet artificial satellite were the following: altitude at perigee – 225 km, at apogee – 1670 km and apogee of the orbit was situated in southern hemisphere at the latitude $\sim 45^\circ$. Telemetry system was switched on 2 - 3 times per day on the orbits passing over the territory of USSR. Points of acceptance of telemetry information were deployed also above the territory of USSR. There was no memory elements on board the satellite and thus the information about the cosmic rays encompassed only the latitudes and longitudes of USSR and the altitudes in the range of 225 to 600 km.

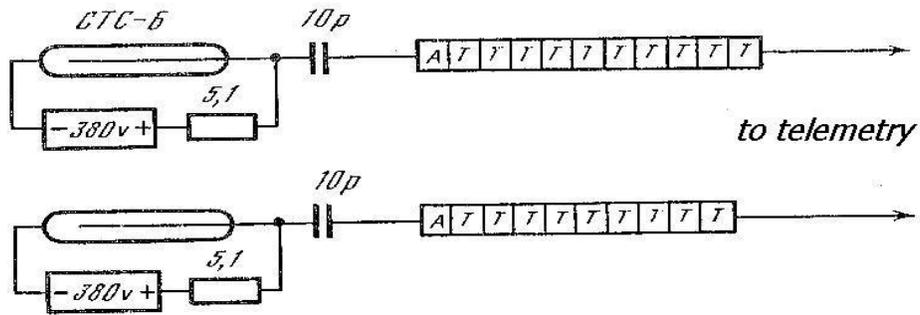


Fig. 2. Principal scheme of the detectors and of electronics placed onboard of the second Soviet satellite. A – amplifier of the signal from counter, T – trigger of the reducer of the count rate.

The flight of the second satellite confirmed the pieces of knowledge of cosmic rays: the observed latitudinal and altitude dependence of cosmic ray intensity did not contradict to already obtained data, and just on a single orbit there was registered anomalously high counting rate of detectors (Fig.3), which was interpreted as penetration of the solar particles into the polar regions of magnetosphere of Earth. Later, it became clear that on November 7, 1957, the satellite observed the precipitation of the radiation belt particles into the upper layers of the atmosphere due to the action of moderate geomagnetic activity [15, 16].

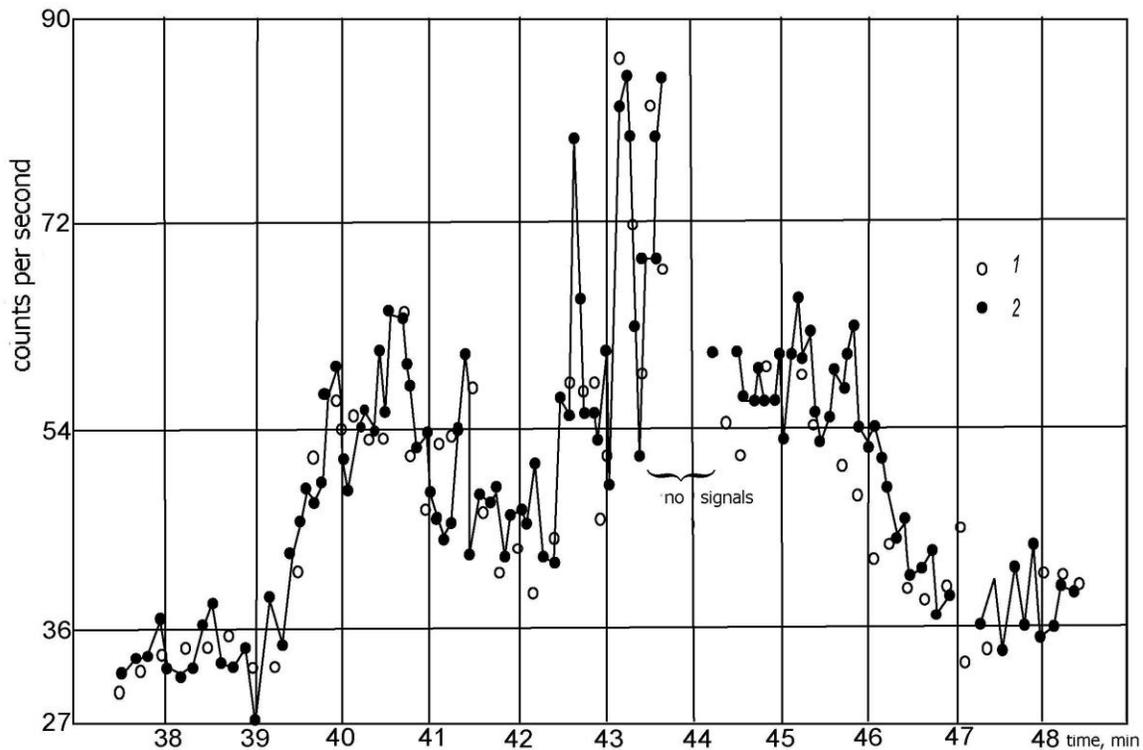


Fig.3. Variations of cosmic ray intensity during one of the orbits of the second satellite over the northern regions of USSR. Nowadays it is clear that it was precipitation of the particles from outer radiation belt during geomagnetic activity. Numbers 1 and 2 correspond to read-outs of the two detectors.

Discovery of radiation belts of Earth (RB) strongly changed the plans for future research works, pushing aside the cosmic ray investigation. Nevertheless, in all possibilities, during the flights of various space vehicles, there were conducted measurements of cosmic rays too. The space flights, where detectors of primary (galactic) as well as of solar cosmic rays were used, are:

Flights to Moon;

Interplanetary flights: to Venus, Mars, and interplanetary probes ;

Heavy satellites Proton;

Selected satellites of series Cosmos.

2.1.1. Lunar program.

By the launch of three satellites and thus demonstrating the possibilities of cosmic technology of USSR, which was important during the non-quiet time period, it became necessary to provide new steps in the space program, since the launch of just few satellites would not induce large resonance. And the task number one became Moon. It was necessary to send out the rocket to the Moon to demonstrate that Moon was reached. There were also discussed the variants of the explosion of atomic bomb on lunar surface. Fortunately such type of suggestions did not find support. First successful launch was on January 2, 1959. The second was launched on September 12, 1959 and the third one on October 4, 1959, just two years after the launch of the first artificial satellite of Earth. The task of the first two flights was arrival to Moon's surface, the third one was aimed to take photos of the reversed side of the Moon. The first space vehicle did not reach the Moon although it approached relatively closely to its surface (5000 km). Second device reached the lunar surface, and before it crashed and was destroyed by hitting the surface, it succeeded to measure the magnetic field and radiation in the vicinity of Moon. The flight of that device was observed by the Jodrell Bank Observatory in UK. In Europe just that observatory had a large antenna capable to receive weak radiosignals. The Observatory confirmed the hit of the apparatus on lunar surface just in the computed time. The flight of lunar station and its "meeting" with the Moon on September 14, 1959, were absolutely important events in the history of space research and they became the triumph of the of the Soviet rocket and electronic technology. More details about the lunar flights can be found in [17].

The third device made the snapshots of the lunar surface, and although they were not very bright, they were the first snapshots of the reverse side of the Moon. It became clear that the reverse side of Moon is similar to the visible one, there are craters, seas and other peculiarities. In the atlas of the reverse side of the Moon issued, the peculiarities were assigned the names of important persons, who contributed to the discussions on origin of the Moon, to the new hypotheses etc.

On all three of the Soviet lunar devices, named subsequently as Luna-1, Luna-2 and Luna-3, there were placed our scientific instruments for measurement of cosmic ray particles and particles of radiation belts of Earth.

Especially large complex of the instruments was onboard of the stations Luna-1 and Luna-2. In the instruments they were scintillation and gas-discharged counters with various screenings. The complex of devices of the first lunar missions is described in [18]. The main task of the flight of the station Luna-3 was to take photographs of the Moon and that is why the place and weight for other devices was very limited.

Onboard of all three lunar missions our device was working very well and interesting results were obtained. Along with the US probes Pioneer-1, -3, the Soviet probes have flown through the whole thickness of radiation belts and they determined the spatial distribution of radiation at large distances from Earth and at slightly larger latitudes. In Figure 4 the dependence of ionization in the crystal NaJ(Tl) along the trajectory from the distance and of geomagnetic field lines latitudinal projections for the stations Luna-1 and Luna-2 is shown.

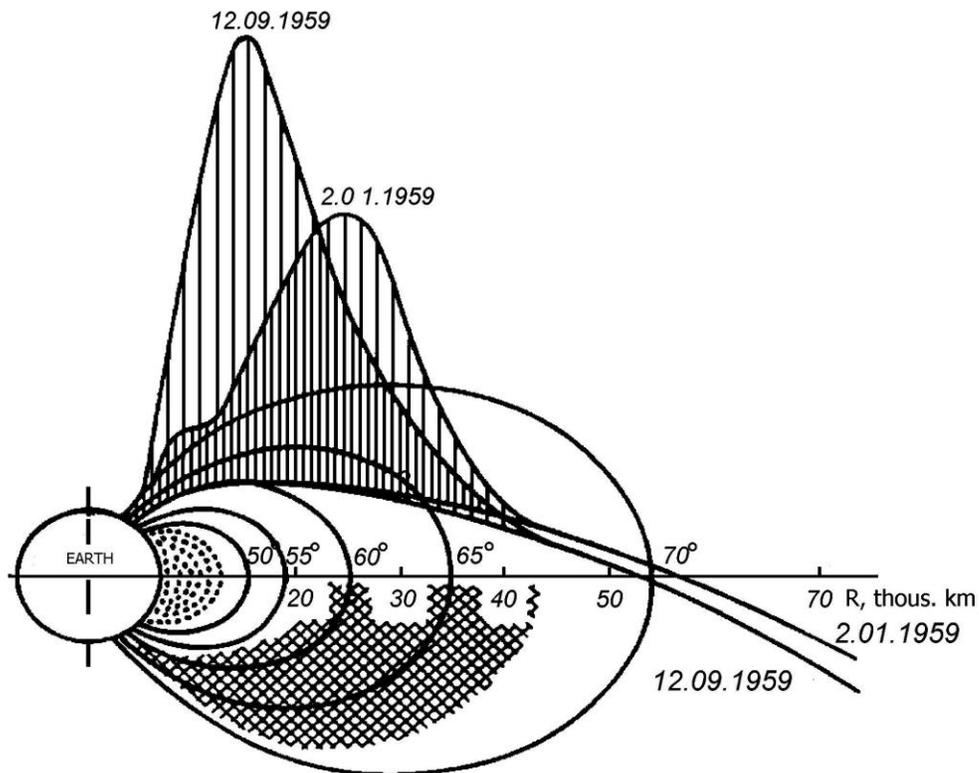


Fig.4. Ionization in crystal NaJ(Tl) during the flights of the space stations Luna-1 (2.01.59) and Luna-2 (12.09.1959) through the radiation belts of Earth.

It is apparent that two different flights at close trajectories have shown different structure of outer radiation belt, indicating thus the instability of outer belt – temporal variations of particle flux within the trapping region. Measurements on Luna-1 for the first time allowed to estimate the altitude profile of the intensity of trapped particles along the geomagnetic field line. Luna-1 crossed three times the same geomagnetic field line, namely at altitudes 8700, 11000 and 18250 km. At those altitudes the scintillation detectors observed the energy deposit in the crystal corresponding to 30, 65 and 145 GeV/c. Such values of energy deposition show that the altitude profile at larger distances from the Earth is weaker than that observed at low altitudes, where the Earth's atmosphere plays a more important role in the losses of trapped particles.

This part of the lunar mission programme laid the foundations of the beginning of systematic research of radiation belts of Earth, which was subsequently continued intensively with use of other space vehicles (Electron, Molnija, geostationary satellites etc.). Onboard of these satellites there were provided studies not only of radiation belts, but also of the magnetosphere in its complex, its structure, variations, relations to the solar activity processes and other effects.

In the following time the research of radiation belts of Earth were not conducted in the lunar programmes which was targeted exclusively for studies of lunar environment. The

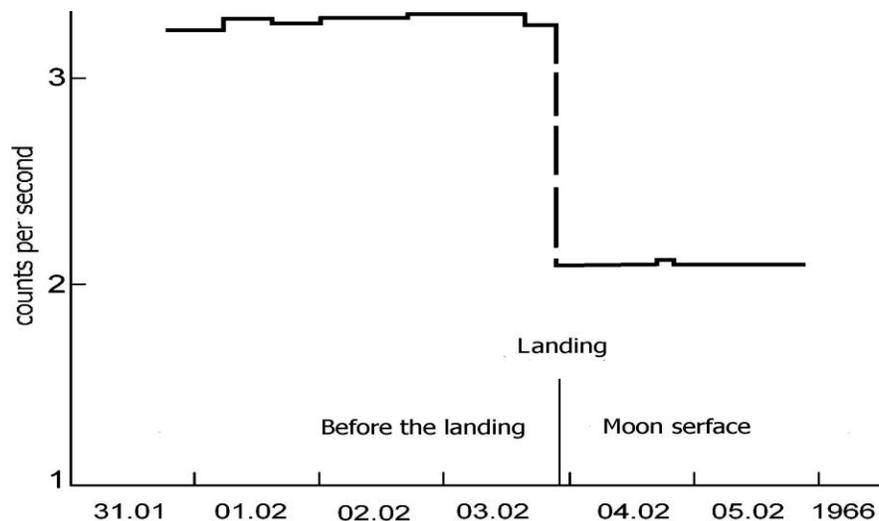


Fig.5. Flux of radiation in the open space and on the lunar surface according to data of the gas-discharge counter onboard the station Luna-9.

studies of the Moon, however, included also the fluxes of galactic and solar cosmic rays, the radioactivity of the lunar surface and fluxes of lunar albedo particles, i.e. of secondary particles emitted from the surface due to the interaction of galactic and solar cosmic rays

with nuclei of the materials of the surface. Such measurements were done on all stations from Luna-4 till Luna-16 as well as during the flight of automatic interplanetary station Zond-3 (July – December 1965) which provided the photos of the reverse side of the Moon once more. Among the Luna's missions specific place belongs to the station Luna-9 which landed softly on the lunar surface on February 3, 1966. Results of our experiment operated there are shown in Figure 5. Fluxes of cosmic rays in the open space must be two time larger than on the lunar surface where the field of view of the instrument was lower by factor of 2 due to screening by the body of Moon. It appears that the surface flux was lower only by factor 1.6, not by 2 as expected because of the radioactivity of the surface plus albedo cosmic ray particles. Assuming these factors, it was possible to estimate the radioactivity emission of the surface of Moon, which was close to the radioactivity of the Earth's ground [19]. This result has shown that there is no dangerous radiation on the lunar surface, and that a man can stay there for long time without specific worrying.

Speaking about the investigations of the Moon from more general point of view, not only on relations to cosmic rays, it is necessary to recall the phenomenal success of US scientists accomplishing the landing on the Moon and safe recovery to the Earth of all astronauts visiting the Moon. For the first time the man came to Moon in 1969 and after that the expeditions were repeated five times. There is extended literature describing these activities. These flights have shown principal possibility to establish on the Moon the scientific stations for the long term operations, including also cosmic ray observations. Cosmic ray research on the Moon poses a number of substantial advantages in comparison with Earth's research, since Moon more than 80% of the time is in the open space, and only 20% of the total time it is in the distant magnetospheric tail, where the screening by the magnetic field is not significant. This means that measurements of cosmic rays on the Moon or in its vicinity, from the lunar satellites, are not affected by the influence of Earth's magnetosphere, which is not the case of inner-magnetospheric satellites of Earth flying even behind the magnetospheric boundaries into near interplanetary space (Soviet satellites Prognoz, US satellites IMP etc.). Because of that onboard of all lunar space stations landed on the Moon, on lunochods or on the artificial satellites of Moon, there were instruments for investigations of solar and galactic cosmic rays.

2.1.2. Satellites “Proton” and others studying very high energy cosmic rays.

In the former USSR due to initiative of S.N. Vernov there were done for the first time studies of cosmic rays onboard heavy artificial satellites. The commencement was done by 4 heavy satellites of the series Proton, where they were provided the first direct measurements of the energy spectra of all particles of cosmic rays up to energy 10^{15} eV, as well as dependences of proton-proton interaction cross section in the range 10^{11} - 10^{12} eV.

In 1960es there were provided intensive development and testing of new rockets both in USSR and in US. In USSR along with the rocket which launched into the space the first satellites of Earth and sonds towards Moon, in 1962 the rocket of the type Kosmos was constructed, and in 1965 started the tests of the new rocket which was at that time the most powerful one and was later used for the launch of the heavy satellites not only of

Russian production but also for many satellites of other countries – rocket Proton. Its name was originated from the name of satellites of the type Proton launched by that rocket in 1965. The history of those launches is the following: when the time for the tests of the new rocket capable to launch onto the Earth's orbit several tons, approached, there were discussed two possible loads: the several tons of the sand or the scientific instruments. Of course the sand was more simple load and there was no risk if the launch is not successful. Nobody at that time was constructing any scientific instrument of such weight and to launch a unique scientific instrument for the first testing flight was risky. What will happen if the launch fails? And the deadline of the flight was approaching, only less than a year remained. However, the Institute of Nuclear Physics of the Moscow State University suggested a scientific task, requiring to carry out the heavy device, and made a commit oneself to construct such apparatus until the required time deadline (there was already hope that also people dealing with the construction of rockets will be delayed). The scientific task consisted in research of energy spectra and of composition of galactic cosmic rays in the range of energies 10^{11} - 10^{14} eB. Measurement of energy of such particles requires its stopping in the volume of the detector system itself. Stopping of the particles in the device allows to determine their energy, however the range of protons and production of secondary particles inside the system at such high energies is equivalent to the thickness more than a meter of iron, i.e. the absorption requires the device of very large volume filled with heavy material (lead, iron etc.). Acceleration of charged particles to such high energies was impossible by means of accelerators in laboratories and the planned experiments aside the astrophysical tasks as

measurements of energy spectra and of chemical composition of cosmic rays, were promising in the sense of nuclear physics aspects, as understanding the behavior of cross-section of proton and/or nucleus – nucleus interactions of heavier elements at the increased energy.

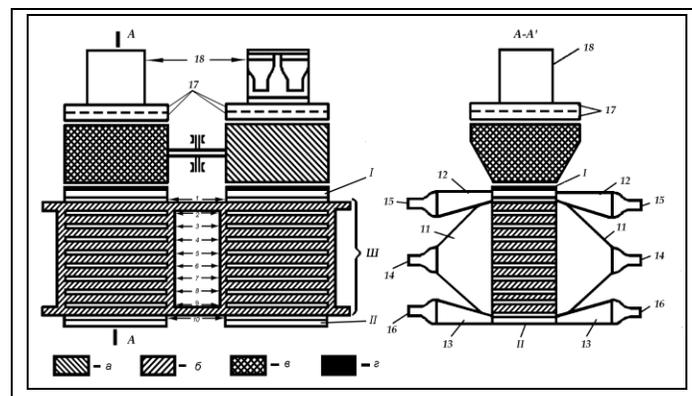


Fig.6. Scheme of the device SEZ-14. I – detector of interactions ; II – lower scintillation detector; III – ionization calorimeter; 1 – 10 – scintillators of the detector of energy; 11 – diffuser of the detector of energy; 12 – diffuser of detector of interactions; 13 – diffuser of lower scintillation detector; 14 – 16 – photomultipliers; 17 – charge detector (doubled proportional counter); 18 – detector of the direction ; a – absorber; b – iron; c – carbon; d – lead;

At that time for measurement of energy of cosmic rays in the ground-based experimental equipments they were widely used the ionisation calorimeters developed earlier in USSR laboratories [20]. Such methodology was applied also on satellites Proton as well as on couple of others, launched later with purpose of similar-type studies. The method of measurement was proposed by N.L. Grigorov who led the research oriented on construction of such type of devices and analysis of data obtained. On satellite Proton-1 there was placed the device SEZ-14 (acronyme of Russian words spectra, energy and charge up to 10^{14} eV) with the weight around 7 tons. The complex device SEZ-14 along with the calorimeter included also detectors of charge of particles – ionization chambers and the target composed of graphite and iron, where the interactions with the material took place. The construction of SEZ-14 is schematically shown in Figure 6. Even for the Institute of Nuclear Physics of the Moscow State University (further Institute) , the design and construction of that complex device within short time interval required enormous effort. According to the instruction of headquarters (S.N. Vernov) for the construction of that apparatus have been thrown up all resources of the Institute including the financial ones. Almost the whole potential of mechanical workshops, and in 1960es it was far not negligible, and large group of electronic engineers was involved in works of construction the apparatus for the satellites of type Proton. The authorities of S.N. Vernov and N.L. Grigorov made possible to prepare a prototype of the device SEZ-14 and of its basic elements (construction elements, fixation of the iron absorber) by utilizing the power of construction department, where the rocket-carrier and the satellite itself were elaborated. This was significant component of the succesful “production” of the device, however, all main questions of the design of equipment were discussed and decided in the Institute: the device was equipped by extensive electronics: e.g. it involved several hundreds of pulse amplifiers. Before satellites Proton such extensive and complicated devices were not constructed and launched. The team of Institute accomplished a scientific record by construction of the device within very short time - 9 months. That device was working around 3 months in space without any failure.

During the flights of satellites Proton-1,-2,-3 a unique results about the stiff change of the slope of energy spectra around energy of protons $2 \cdot 10^{12}$ eV were obtained [21]. Until now this results are not confirmed and not declined. At the same time the slope of energy spectra of the sum of all cosmic ray primaries (protons, He, heavier elements) remained without the bend, which is in agreement with the results of other indirect measurements. If the spectra of protons is really bent with significant change of the slope, this means that in the high energy part of the spectra of primary cosmic rays there must exist the change of chemical composition of primaries with enrichment of heavy elements, since the fraction of protons at high energies is negligibly small. This means that corrections into the mechanisms of acceleration in the source must be included, requiring the predominant acceleration of nuclei with $Z > 2$. Importance of those conclusions is evident, however, it is desirable to have higher confidence in that aspect.

To confirm that result and to shift towards measurements at higher energies, the new device with geometric factor increasing by factor 10 named IK-15 (Ionization calorimeter up to 10^{15} eV) was constructed for Proton-4. However results from Proton-4 did not give

unambiguous result on the bend of proton spectra. A couple of more flights with the device (table 1) gave no clear reply to that question.

Methodological reasons of the change of slope of energy spectra may lie in the nature of the energetic particles themselves, namely in the creation of secondary particles produced in the calorimeter where the energy of secondary particles moving in all directions is measured, including those particles moving into the charge detector, which, in the case of protons must detect as a single charged particle. With the increasing energy of primary particle, the number of secondaries produced in the *material* of the device increases too. This effect, named as reverse flux of particle, is well known. Appearance of particles of the reverse flux in the detector of charges “converts” the event of detection of proton into the event of particle with higher charge which may lead to the loss of count rate of protons. Since the effect of reverse flux increases with the increase of energy of primary protons, the number of “not counted protons” increases too. This may lead to the observed bend of proton energy spectra. Problem of the effect of reverse flux from ionisation calorimeter causes serious obstacle for correct measurement of the energy spectra of protons at high energies. Analysis of tracks in photoemulsions exposed to cosmic rays at Intercosmos-6 was done in collaboration with other laboratories, one of them was IEP SAS Kosice.

Table 1.

Earth orbiting satellites with measurements of high energy cosmic rays

Satellite	Year	Device	Wight of device (in tons)	Time of active work in space	Comment
Proton-1	1965	SEZ-14	7	3 months	
Proton-2	1965	SEZ-14	7	3 months	
Proton-3	1966	SEZ-14	7	3 months	
Proton-4	1968	IK-15	12,5	8 months	
Intercosmos-6	1972	Photoemulsions	2,4	4 days	Device returned to the Earth
Cosmos-1543	1984	SOKOL	2,4	27 days	
Cosmos-1713	1986	SOKOL	2,4	25 days	

To struggle with the reverse flux, in the device called SOKOL (acronym from the russian words of the main task of experiment – composition of cosmic rays), working on satellites Cosmos-1543 and Cosmos-1713, launched almost 10 years after satellites Proton (table 1), the directional Cherenkov detectors of not large dimensions, were used for measurements of protons $Z=1$ and of alpha particles $Z=2$. This allowed to a large

extent to eliminate the effect of reverse flux on determination of charge. Furthermore, the picture of passing the particle through the device was visualized, so that it was possible to set off the particles as well as the electromagnetic cascades produced by them in the alignment of the device. This approach allowed to determine the energy of particle with better confidence.

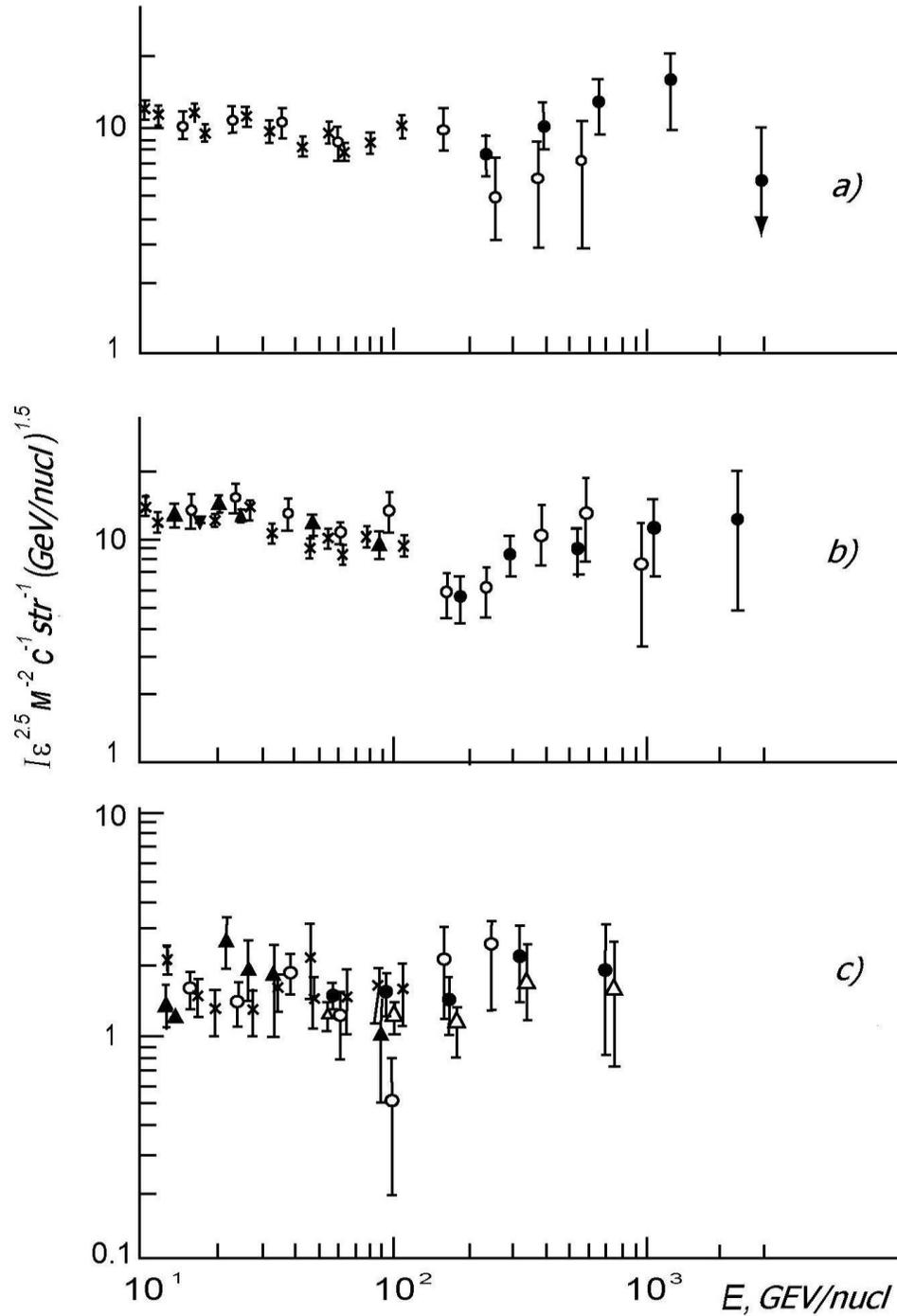


Fig.7. Energy spectra of nuclei of carbon C (a), oxygen O (б) and iron Fe (в) in the region of high energy according to the results of flights equipped with the complex device SOKOL.

The experiments onboard Cosmos-1543 and Cosmos-1713 with the device SOKOL have shown that this device permits to fight effectively with the effect of reverse flux. However, the unambiguous reply to the main question about the shape of primary proton spectra was not achieved because the operational time of the satellites was less than one month and the statistics on protons obtained was insufficient for the substantiated conclusions. For the conclusive settlement of the important question there is requirement to launch similar type of experiment for longer time measurement in space. Until now such experiment was not conducted yet. As an alternative may be considered the experiment Atik run in the frame of international collaboration on balloons detecting cosmic rays at high altitudes over Antarctica [22, 23]. Figure 7 shows the energy spectra of C, O and of the group Fe. Fitting the spectra by power law shape, the index is $\gamma=2,5$. Almost the same slope is obtained for the energy spectra of He nuclei. Ratios of cosmic ray fluxes at different energies characterizing the composition of particles at particular energy, are practically the same as those at low energy. This means that in the frame of that approximation, cosmic ray composition remains almost the same in the energy range from 1 GeV/nuc1 to 1000 GeV/nuc1. At higher energies there are indications of enrichment of heavy nuclei in galactic cosmic rays.

Let us mention that these experiments allowed to shift with observed energies of cosmic rays up to almost 2 TeV/nuc1 for nuclei C and O. Statistical errors in this energy range are still large. It is needed to continue such type of measurements to accumulate higher statistics, especially at high energies. Utilizing the equipment SOKOL for this aim is an adequate approach for this task: it is necessary to enhance the duration of the measurements by factor of 10-20, which is fully possible with using the existing tools of space technology.

Along with that, the Institute prepared proposals for a couple of new experiments qualified to move to even higher energies of cosmic rays on the satellites [24, 25]. The experiments described in the above mentioned publications are now under discussion and they are planned to be accomplished in nearest years.

On satellites Cosmos-1543 and Cosmos-1713 there were observed also heavy nuclei of cosmic rays in the energy range 50-1000 GeV/nuc1, what allowed to obtain the energy spectra of nuclei of He, C, O and Fe [26].

Important data on primary cosmic rays have been obtained recently from the experiment Pamela installed on the Resurs-DK1 satellite launched on low altitude nearly polar orbit in June 2006. More details about that mission, international collaboration and publications can be found at <http://pamela.roma2.infn.it/index.php>. Description of the experiment can be found e.g. in [27]. In mission Pamela there was discovered increase of the fraction of positrons in electron-positron component of cosmic rays with increase of energy, ratio $J^{+}/(J^{++}+J^{-})$ [28]. This may be a signature for the existence of dark matter. Or, alternatively, there may be another additional source of positrons producing them with

efficiency increasing with energy. The data on positron component are reliable due to high statistical accuracy of measurements. The spectrometer has a permanent magnet and separation of electrons and positrons is reliable. The energy of particles is measured sufficiently accurately with the help of calorimeter. The excess of positron fraction and its increase with energy is confirmed recently in mission Fermi [29].

2.2. Solar cosmic rays.

One of the admirable property of the galactic cosmic rays is the stability of its intensity in time. Above this “background” they were simply detached sudden strong increases of cosmic ray intensity related to the powerful processes on the Sun. It became clear that the Sun generates from time to time strong fluxes of energetic particles. They obtained the name solar cosmic rays (SCR). Powerful solar events appear relatively rarely, while less power are observed more frequently, as it is usual for nature.

First observations of SCR have been done with help of instruments on the ground sensitive only to higher primary energy (> 1 GeV). The experiments on balloons in the stratosphere could observe particles with lower energy threshold (>100 MeV). Measurements at high altitudes utilizing the satellites of Earth and other space vehicles allowed to observe less powerful effects, and until now more than 1000 events with energetic particle emissions connected to solar flares, have been registered. While the first observed events in energetic particles have been related to the effects of very high power, and only those could be detected only with ground based devices, nowadays the instruments on satellites and space probes allows to see practically all increases of SCR flux reaching the vicinity of the Earth. At present remain not observed only few cases of not powerful solar events on the reverse hemisphere of Sun, from which the energetic charged particles did not reach the Earth’s vicinity or the site of the interplanetary probe. To exclude these gaps it is supposed to “patrol” the space around the Sun at various heliolongitudes including the reverse hemisphere of the Sun. The solar mission STEREO are already fulfilling this programm.

Most frequently the energy of accelerated solar particles does not exceed 10 MeV/nucl (1 MeV for electrons). Such flares during the solar activity maximum occur once per week. Associated particles are observed beyond the magnetospheric boundaries, within its peripheral regions or in the polar cap. Less frequently, typically once per month appear the flares accelerating particles to energy ~ 100 MeV/nucl and higher. Such particles in the polar latitudes penetrate into the atmosphere of Earth and can be observed during the flights of high altitude balloons. In even more rare events, observed typically once per year, particles are accelerated to energy 1 GeV. Extremely powerful events occurring 2-3 times per 11-year cycle of solar activity, are characteristic with very high fluxes of accelerated particles with maximum energy 10 GeV or even more. Most frequently they are observed by neutron monitors distributed over the world.

2.2.1. Ground based observations of CR variability and SCR.

Interplanetary magnetic field are partly screening the flux of galactic cosmic rays. Screening effect, especially at lower energies, is variable in time and thus cosmic ray intensity observed near Earth is temporary variable. Both regular and quasi-periodic (e.g. diurnal, ~27 day, ~11 year) variations are connected with the solar activity and provide the informations about structure of interplanetary magnetic field and on solar wind in the heliosphere. More detailed review on cosmic ray variations can be found in [30,31] and in monographs [32, 33]. Research of cosmic ray variations requires long time series of homogeneous measurements. First instrument devoted to this task was ionization chamber developed and constructed by A. Compton in 1934. In USSR the measurements of cosmic ray flux with purpose to study its variations started in 1936 by Yu. G. Shafer in the Yakutsk pedagogical institute with using the independently constructed ionization chamber – electrometer. These works have been broken by the world war, in which Yu.G. Shafer went through the fighting course from Stalingrad to Berlin, and he recovered the measurements of cosmic rays in 1947 in Yakutsk Institute of Space Physics and Aeronomie via construction of ionization chamber ASK. By this instrument the network of stations over the whole territory of USSR was equipped.

Before and during the International Geophysical Year (1957) the whole world network of cosmic ray stations was equipped by neutron monitors developed by J. Simpson in 1948. Such equipments were installed also in USSR, among them e.g. in IZMIRAN (Troitsk, near Moscow), in Apatity (Polar Geophysical Institute) where the measurement is continuing until present. One of NMs operating in Russia until now is seen in Figure 8.



Fig.8. Neutron monitor in Yakutsk

Neutron monitor (NM) consists of the group of proportional counters. There are used two types of counters, namely those filled with the gas including a high concentration of the isotope ^{10}B or with ^3He . The counters are surrounded by the moderator serving to slow down the neutrons before entering the counter and also to reflect low energy neutrons. The moderator is inserted into the lead producer surrounded by the outer moderator – reflector. This is rejecting unwanted low energy external evaporation neutrons produced in the local surrounding. During the years the neutron monitor construction was changed. First the IGY monitors were used and in some places they are used until now. For that

one the moderator and reflector material is paraffin. In 1964 the network of neutron monitors with larger counting rate, the supermonitors (NM64), replaced in many places the original IGY NMs. The network of NM64 in USSR was done under leadership of S.N. Vernov and main role in the constructions belongs to N.N. Kapustin, the engineer in Polar Geophysical Institute. The NM64 monitor has a low density polyethylene moderator and reflector. The differences are also in geometry and tubes. More about neutron monitors can be found e.g. in [34].

Important are high mountain NMs having higher statistics. One of them was constructed at Lomnický štít (2634 m above sea level, High Tatra mountains, run by IEP SAS, one of the authors (KK) is PI of it since 1982) during IGY as a contribution of Czechoslovak physicists to IGY activity. It is operating until now (data at <http://neutronmonitor.ta3.sk>). Let us mention just one result: since 1950es there was assumption that solar protons accelerated to high energies and interacting with residual solar atmosphere can produce neutrons which can be detected even at the Earth's orbit. After 30 years, during the solar flare on June 3, 1982, the increase corresponding of solar neutrons at two high altitude NMs in central Europe, namely at Jungfraujoch and at Lomnický štít, have been observed in coincidence with satellite measurements of increased flux of high energy gamma rays reported by E.L. Chupp. High statistical accuracy of measurements (5 min resolution at that time) at Lomnický štít contributed to that finding [35]. Selected results obtained with use of that NM can be found in [36].

2.2.2. SCR observed on balloons.

Measurement of SCR on balloons are filling the energy range (100-1000 MeV) between that observed by ground based devices and the measurements on satellites and space probes. First observations of SCR in the stratosphere were registered independently in US, Minneapolis, Fort Churchill and in USSR, Murmansk, in 1958. Regular measurements in stratosphere in USSR started in 1957 by the group of A.N. Charakhchyan in Moscow (Dolgoprudnyj), in the vicinity of Murmansk and epizodically in Yakutsk and Tixie (Yu.G. Shafer, V.D. Sokolov, A.N. Novikov), as well as in Simeiz, Crimea (Stepanyan). Later, since 1962, the regular flights of radiosonds began in Apatity (LLL, one of the authors). Measurements have been conducted during short time flights on rubber balloons by

radiosonds with use of two Geiger counters; a short pulse was transmitted to Earth in the case of single detector count, longer pulse meant the coincidence in two counters. Between the counters there was metallic screen for the registration of charged particles in two energy channels. The needle of the barograph interrupted the transmission on seven contacts – serving as measurement of residual pressure of air above the ballon. Figure 9 shows the scheme of radiosond RK-2 of A.N. Charakhchyan using valves, which was later replaced by semiconductors at all devices of regular measurements in Moscow, Mirnyj and Apatity. Figure 10 shows the results of measurement – altitude profile in the coincidence channel during four solar flares with SCR emission. Figure 11 shows the moment before the launch of radiosond of cosmic rays in Apatity observatory.

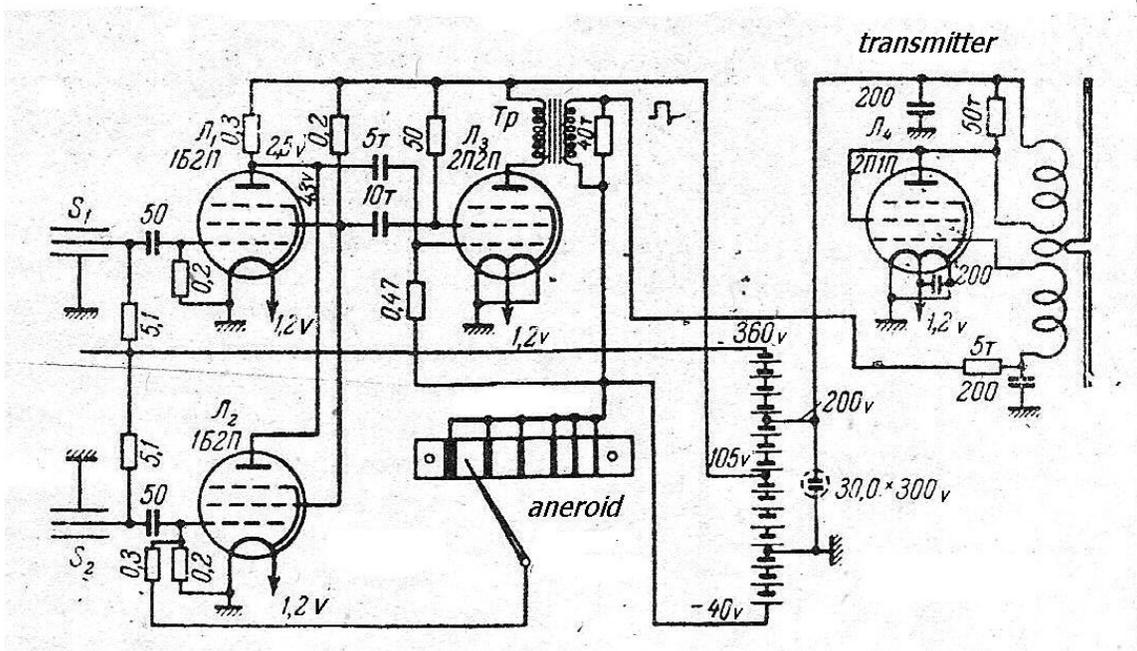


Fig.9. Electronic scheme of the experiment measuring cosmic rays on radiosond.

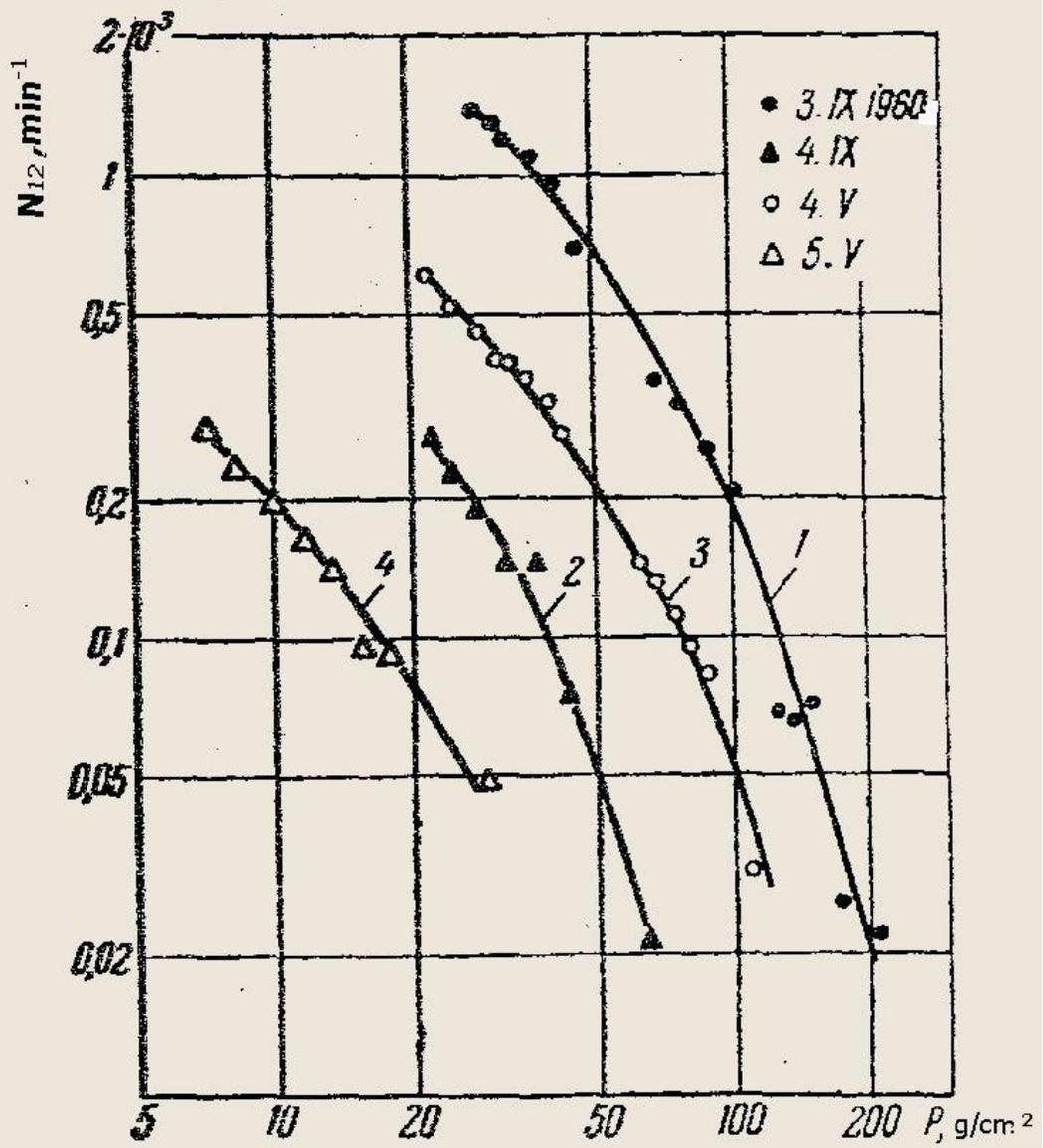


Fig.10. Altitude profile (scale in min^{-1}) of the count rate of coincidence pulses of two GM tubes on radiosonds during four different SCR events.



Fig.11. Academician B.M. Pontecorvo visiting the launch site of radiosonds in Apatity before one of the launches.

Along with the measurements of SCR described shortly above, the regular stratospheric measurements of cosmic rays are run with the purpose to check the cosmic ray variations at different depths in the atmosphere by the group in Physical Institute of Russian Academy of Sciences, Moscow (G.V. Bazilevskaya and Yu.I. Stozhkov). Figure 12 shows these measurements [37, 38].

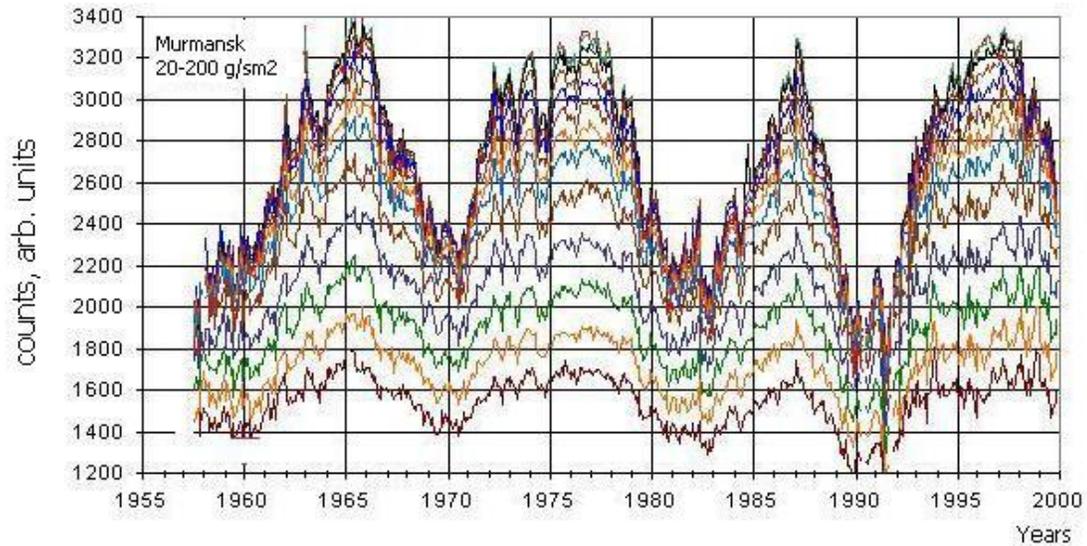


Fig.12. Temporal profile of cosmic ray intensity measured over Murmansk since 1957 at different depths of the atmosphere [37, 38].

2.2.3. SCR observed on satellites and space probes.

In USSR, above mentioned S.N. Vernov founded the service of steady monitoring of cosmic rays in the upper layers of the atmosphere – daily launches of the same type of device in Moscow, Apatity and sometimes also in the southern part of the country (region of Alma-Ata). Along with that, during each flight of the satellites where it was possible to put the scientific device measuring cosmic rays, such device was installed on board. By this way the detection of solar and galactic cosmic rays was conducted during all flights to Venus and Mars, as well as during the flights of several interplanetary stations Zond.

Especially successful was the flight of Venera-4, when the measurement of cosmic rays was done over the whole route. At that time was the period of enhanced solar activity (1967) and devices observed large number of solar events. During the subsequent flights to Venus they were done many measurements, however, flight of Venera-4 was most impressive because it was first really succesful one accompanied by obtaining of interesting information over long time period including that of the landing on Venus.

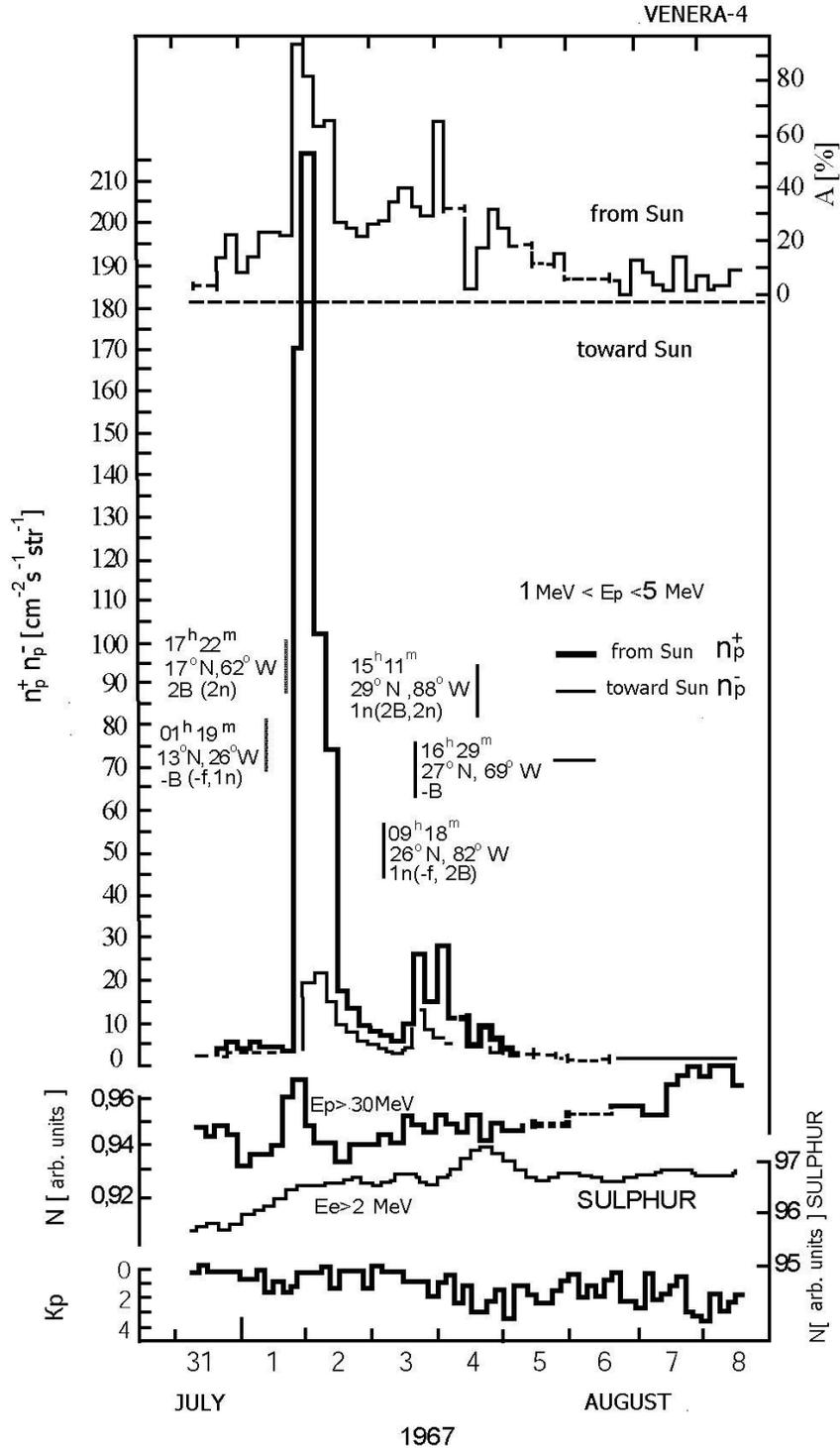


Fig. 13. Fluxes of particles from a couple of solar flares during July-August 1967 according to measurement of instrument AMS onboard Venera-4. Upper curves indicate the anisotropy of protons $E_p > 1$ MeV. Thick line is proton flux from the Sun, thin is toward the Sun.

In majority of events the particle increases at relatively low energy were not intense. Thus, they were observable only away from the magnetosphere, not inside it. Especially satellites with low inclination did not see them because of geomagnetic field filtering. Onboard Venera-4 protons and heavier nuclei were detected with use of two identical semiconductor detectors looking into opposite directions, and thus allowing to observe partial spatial anisotropy. If the particles are emitted by Sun, its motion is directed by the field lines of IMF approximated by Archimedean spiral (with angle about 45° to the sunward direction at 1 AU). These field lines are not totally smooth – they are superimposed by the irregularities of various dimensions, and charged particles are scattered on the irregularities, sometimes changing its direction of velocity towards the opposite one. Due to such scattering during the lengthy stay in IMF, the particles “forget” their initial direction, and their angular distribution becomes to be close to the isotropic one. Thus the anisotropy is in such cases equal to zero. The flight of space probe Venera-4 has shown that such situation is met relatively frequently, however, at the same time the devices looking toward the Sun observed over several hours much higher fluxes of particles in comparison with those looking in the opposite direction (Fig. 13). This means that in the given events the Sun is emitting over long time, sometimes up to the day, rather large fluxes of particles, and the field lines of IMF controlling their motion were sufficiently smooth, without scattering, so that there was low number of particles flowing in opposite direction. Such picture corresponds to high positive anisotropy of particles fluxes from the solar flares. Such type of events later have been observed rather often, they obtained the name of events without scattering, however Venera-4 was the first one space apparatus which observed this phenomena. Now it became clear that anisotropy of solar flare particles in interplanetary space is developing in general quite regularly. First the anisotropy is sufficiently high and it has direction from the Sun along the interplanetary field line, later it is decreasing and becomes to be directed radially from the Sun, and finally the angular distribution is changed to the form with maximum flux perpendicular to field lines, which is connected with the drift of charged particles in the crossed electric and magnetic field (electric field originated due to motion of the magnetic field line together with the solar wind plasma).

Previous flights around Venus did not give reply to the question about existence of the trapped radiation in its vicinity. Venera-4 has shown that near Venus there is no trapped radiation even at the smallest distances to its surface: when the device was approaching the surface the radiation was not increasing but even decreasing in accordance with geometry (because of screening by the solid body of Venus). This important result is in agreement with the lack of noticeable magnetic field of Venus measured by the team of IZMIRAN during the same mission.

Data from Venera-4 have shown that the Sun disposes with large diversity both in generation of charged particles as well as in creation of conditions in interplanetary space controlling the motion of the particles in the heliosphere. Those particle fluxes which are observed on the Earth’s orbit or in another point of space, are determined by both the conditions of the source (solar flares) and by peculiarities of interplanetary medium, through which they pass on their way from the Sun to the periphery of heliosphere. Propagation of particles brings into their fluxes significant “corrections”: at the Earth’s orbit we observe not the identical temporal profile of the fluxes of accelerated particles; the energy spectra formed at the site of their generation is changed; part of the

accelerated particles is not escaping from the Sun etc. Let us treat e.g. the instant generation and outflow of particles from solar surface. In the simplest case of diffusional propagation of particles, on the Earth's orbit there will be observed the profile extended in time and so called diffusional wave (Figure 14): first particles of high energy arrive (higher velocity), later lower energy particles etc. Comparison of the observed temporal profiles of particle fluxes with the computed ones assuming the diffusion shows that sometimes on the Sun really takes place instantaneous release of particles propagating further diffusively, as it is e.g. in the flare on November 22, 1977 and in the couple of other flares.

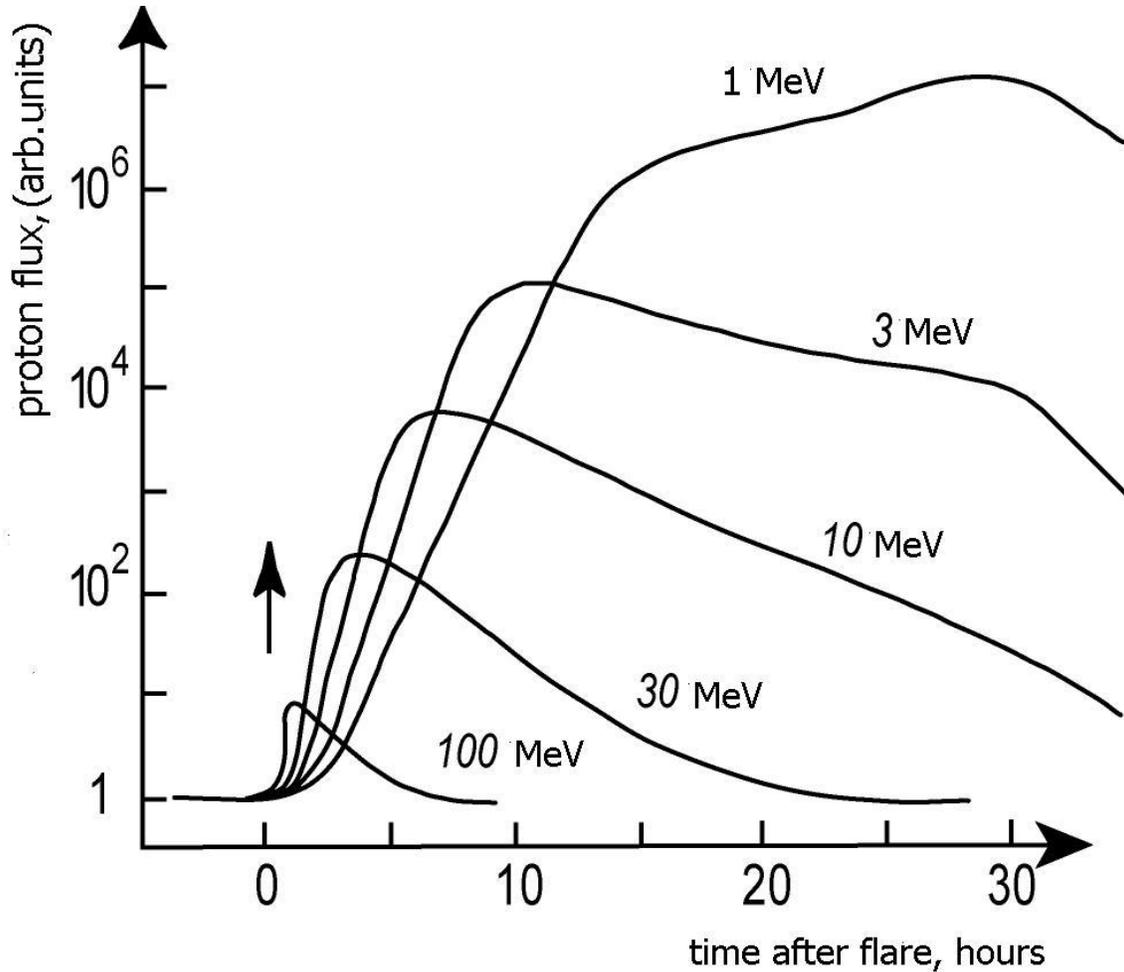


Fig. 14. Schema of diffusional wave of solar protons – temporal profiles of various energy proton fluxes at 1 AU for the impulsive acceleration at the Sun at 1 AU.

Especially for study of SCR and in particular for development of the method of prognosis of powerful solar flares, representing estimates of radiation hazard in space flight, there were constructed satellites Prognoz which started to be launched in 1972. In table 2 there is basic information about the the satellites Prognoz launched in USSR.

Table 2. Dates of launch and orbits of the satellites Prognoz – measurements out of the magnetosphere.

Satellite	Date of launch	Initial apogee altitude (10 ³ km)	Orbital period (days)	Time of active operation (months)
Prognoz-1	14.04.1972	≈ 200	≈ 4	4,4
Prognoz-2	29.06.1972	≈ 200	≈ 4	5,5
Prognoz-3	15.02.1973	≈ 200	≈ 4	12,5
Prognoz-4	22.12.1975	≈ 200	≈ 4	2,5
Prognoz-5	25.11.1976	≈ 200	≈ 4	7,8
Prognoz-6	22.09.1977	≈ 200	≈ 4	5,3
Prognoz-7	30.10.1978	≈ 200	≈ 4	6,8
Prognoz-8	25.12.1980	≈ 200	≈ 4	8,8
Prognoz-9	01.07.1983	≈ 720	≈ 27	8,0
Prognoz-10	26.04.1985	≈ 200	≈ 4	9,3

We must agree that the main task of the Prognoz project – to obtain reply on the question about the causes of solar flares and to elaborate the method of the prediction of solar flares with potential of radiation hazards – was not achieved. However, it gave an opportunity to move forward in the understanding of some acceleration processes and especially of propagation of accelerated particles in interplanetary medium, in the research of recurrent particle fluxes and other phenomena. Summary of the results of the experiments can be found in proceedings [39, 40]. Below we list some basic results obtained with help of satellites Prognoz.

Protons are accelerated in all flares. It was shown that in all solar flares there were accelerated electrons of relatively low energy (> 40 keV), as well as protons (on satellites Prognoz the measurements of protons were > 1 MeV). This fact enabled to exclude from terminology the term “electron flares” which supposed the existence of flares with exclusive acceleration of electrons. Until the flight of satellite Prognoz this opinion was widely accepted and it was assumed that particle acceleration in such flares is due to betatron mechanism with low efficiency for acceleration of heavy particles. It was shown that for all flares detected on Prognoz satellites the electron fluxes including the weakest ones were accompanied by protons [41]. Further research showed that the energy spectra of electrons and protons are similar, if represented as dependence on kinetic energy of particles which requires completely different mechanism of acceleration than betatron one.

Coherent propagation of particles. Unusual mode of the fast propagation of particles was discovered: in the narrow angular interval near the field line connected to the region of flare, the electrons are propagating practically without scattering, i.e. with conservation of angular distribution along the long part of their path from Sun to Earth. This assures high velocity of their motion through the space. During the propagation such “huddle” of particles generates radiowave emission of the type III, for which the

frequency depends on the density of medium where the propagation takes place. This mode of propagation was named coherent. On Prognoz satellites the coherent propagation was observed also for protons [42,43].

To detect the coherent propagation of particles is difficult, since to peg at the the narrow beam of the particles has low probability. Such event on the Earth's surface takes place just 10 – 20 min, and subsequently the beam flowing over the space vehicle is stretched along the field line only at 0.5 – 1.0 AU. Near the Sun the beam has even smaller dimensions, because as per propagation in space its “difffluence” takes place. Furthermore, for the existence of the energetic particle “huddles” they are necessary specific conditions in space, sufficient smoothness of the magnetic field and its focusing in the ecliptic plane.

Energy spectra of protons in interplanetary space during quiet Sun. In the absence of intensive particle fluxes accelerated at the Sun, i.e. in periods of quiet Sun, there are anyway non-intensive fluxes of energetic particles in interplanetary space. The origin of such particle fluxes was not determined for long time. Before the launch of Prognoz satellites the energy spectra of protons and of other particles was known just above 500 keV/nucl. If one artificially extrapolates energy spectra of protons from 500 keV towards lower energies (Figure 15), such spectra impinges on the solar wind. Thus, it was natural to assume that the observed spectra of protons and heavier particles is just continuation – a tail – of the solar wind particles. The nonthermal character of this tail was assumed because with using the Gaussian distribution of solar wind protons with measured temperature (10^4 K) the proton flux must decrease so sharply with energy increase that it is impossible to speak about any agreement with the observed proton flux at energy 0,5-1,0 MeV – the difference will be of several orders. In such case in energy spectra of particles during quiet time there must be one more minimum in the energy range about 30 – 100 keV. It would be interesting to find such minimum, its existence would have principal implication because it would separate fluxes of different nature – having different origin.

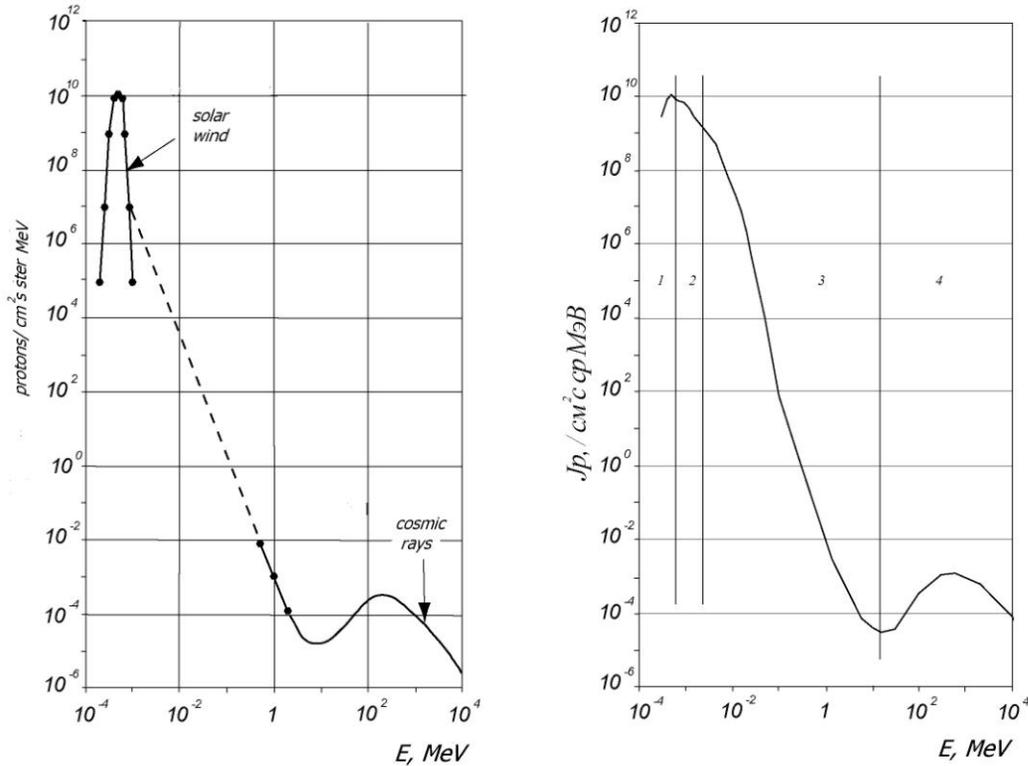


Fig. 15. Energy spectra of protons at 1 AU during quiet Sun according to understanding in 1970es (left) and at present (right). 1 – solar wind, 2 – suprathermal particles, 3 – energetic particles of solar origin, 4 – galactic cosmic rays.

One of the tasks of the satellite Prognoz-3 consisted in measurements of particle flux at energies as close as possible to the energies of solar wind particles. The experiment conducted allowed to measure spectra during the most quiet periods within the active interval of Prognoz-3. Energy spectra was measured down almost to energy 30 keV and no cavern or minima of proton flux was observed. Presently it is clearly confirmed that there are no peculiarities in the energy spectra of particles in the energy range between the energetic particles (<1 M \AA B) and solar wind. For today the energy spectra of protons measured in quiet time period of the Sun is shown in Figure 15 (right).

Interplanetary medium during periods of quiet Sun. Studies of variations of solar particle flux showed that interplanetary space in each given section of the time has some prevalent (characteristic) state, to which it is tending to recover after various types of disturbances. This prevalent state is controlled by the magnetic field of the Sun and by solar wind, which in general are not changing very frequently. In average it is possible to assume that during the time of low solar activity the structure of the fields and of solar wind remain stable during 1-2 or more solar rotations. The structure of interplanetary medium is bound to various active regions on the Sun, affecting thus the properties of the interplanetary space in the solid angle created by the magnetic field lines outflowing from

the active regions. The structure around the Sun is bound to its surface and it is rotating along with that. This is well seen according to solar particle flux at various time scales. According to data from Prognoz-1 and Prognoz-2 the fine structure of interplanetary medium was shown.

On Prognoz satellites it was registered also longer time quasi-stationary structure of interplanetary medium. This emerges from the rate of decay of the solar particle fluxes associated with the flares after reaching the diffusional maxima. The decay rate

is an independent characteristic of the extent of disturbance of IMF and of solar wind velocity. It was found out that for majority of solar particle increases (>1 MeV) during 1972 the decay corresponded to exponential law with the same characteristic time equal to about 16 hours [44]. Even after largest solar flares in 1972 when interplanetary space was disturbed due to passage of strong shock waves, just after few days all characteristics recovered to its original state and the characteristic time of decay rate was again about 16 hours (Figure 16).

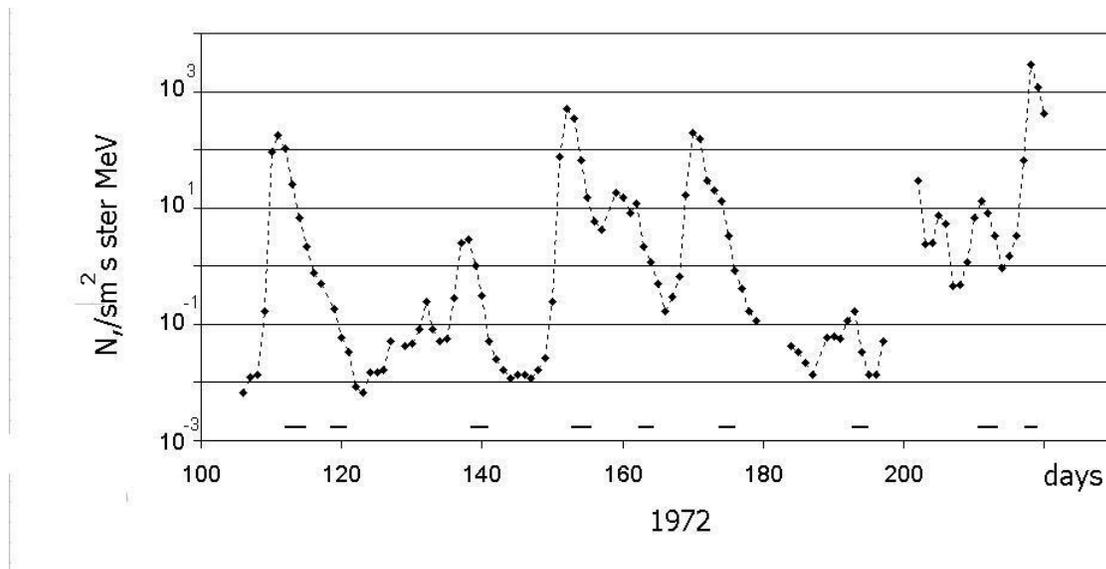


Fig. 16. Fluxes of solar protons observed on Prognoz-1. During 70 days the eight increases of SCR were observed, having exponential profile of decay (energy $E_p \approx 1$ MeV) with almost identical characteristic times $\tau = 16.5$ hours. This shows the evidence of long time period (more than two solar rotations) stationary state of interplanetary medium around the Sun.

The decay phase of particle flux after the maximum in SCR sustains the information about the solar wind velocity, disturbance of IMF and other parameters of interplanetary medium. The extent of disturbance of IMF is one of the main factors of the state of interplanetary medium characterized by the diffusion coefficient of particles in the medium, and the solar wind velocity determines the form of temporal profile of particle flux, the rate of its increase and of decay after maximum.

Various models of particle propagation lead to various laws of the decay profile in the late stage of the event. Temporal profile of particle flux in solar events has a characteristic form. On the Earth's orbit for solar event connected with a single flare, the particle flux

has a rather fast onset, reaching the maximum and subsequently decreasing down to the level before the flare. There are met rather frequently the events with picture described well be the diffusion approximation. In such cases, assuming the impulse source of the particles (time of generation is much less than that of propagation to the site of observation), the temporal profile $J(t)$ in its decay phase has a power-law character and it is proportional to $t^{-3/2}$. In the case of prolonged injection, it is necessary to assume the function of particle source leading thus to the prolongation of the event, however, it is negligibly reflected on the late stage of the event.

If the influence of the solar wind is essential the convective outflow of particles and their adiabatic cooling may be important. Then the decay form is approximated by $J(t) \sim e^{-t/\tau}$ [45-48]. Power law sufficiently well works for high energy particles (> 100 MeV). For particles of lower energy (< 10 MeV) the convective outflow process begins to play much more important role, and the decay is exponential. It turned out that in majority of solar events the fluxes of protons with lower energy (< 10 MeV) have exponential decay, while for particles with energy 30 - 60 MeV the convective outflow is observed too, however less pronounced. Often the particle propagation is accompanied by various processes of additional acceleration which leads to the change of "smooth" temporal profile and then decay can not be described by any single form law. Apart from sufficiently frequent observations of the events with exponential decays, in many studies until now there is not paid corresponding attention to that form of decrease of intensity. If in the decay phase of the solar flare increase the convective outflow of particles and adiabatic cooling are predominant over the diffusion, for the characteristic time of decay the following relation was found [45]:

$$\tau = 3r/2V(2 + \alpha\gamma),$$

where V is solar wind speed, γ - index of energy spectra of particles, r - distance of the site of observation to the Sun, $\alpha \approx 2$ for nonrelativistic particles. The performed analysis indicates that in the considerable fraction of events (up to 50%), when V remained constant during the whole decay phase, τ is satisfactory well described by the form above.

Real measurements are carried on near the Earth in different flux tubes due to rotation of the Sun, where the magnetic conditions are usually different. In some cases the stability of particle fluxes along the longitudes is observed only over short duration. In such cases the two devices placed within a small angular distance (sometimes $\leq 10^\circ$), observe entirely different fluxes. At the same time, relatively frequently, there are appearing the same conditions for particle propagation, over the wide latitudinal extent, what is confirmed by simultaneous measurements at different space devices. In such cases the particle fluxes are constant over the large angular extents (even up to $>100^\circ$) [49].

The conducted long term studies, including almost three full solar activity cycles, have shown that for remarkable fraction (almost half of the solar energetic particles events), the value τ for energies 1 ÷ 10 MeV is equal to 16-20 hours, which is in agreement with the above formula for the typical values of the parameters included. This means that also interplanetary medium during the periods with the events of solar particle emission, is in the state correspondent to that value of τ . Around 20% of events have larger value τ reaching sometimes 50 hours or more [50].

Recurrent fluxes of solar particles. Flights of the first two satellites Prognoz were held in the period of decrease of solar activity, and the devices onboard these satellites often

observed recurrent fluxes of particles, i.e. fluxes persisting in interplanetary space over long time, and as they were rotating together with the Sun. They were established several differing series of such type of fluxes, obtained their characteristics and it was shown that a part of them is connected with the Sun. Most interesting was the conclusion: if the active region emits recurrent fluxes of particles, the energy is not accumulated within the region, and consequently there is no need to release superfluous energy by the explosive manner. This means that the solar flares are not taking place there [51].

Further study of recurrent fluxes has shown that they are most frequently connected with so called coronal holes – regions with lower level of emission in soft X rays, which are also the sites of origin of high speed solar wind.

The longer intervals of stationary conditions in interplanetary space can be found during the periods of lower solar activity via the recurrent fluxes of low energy particles, having the spatial structure saved over the long time. Recurrent fluxes sometimes exist over several rotations of the Sun, what was observed not once also on satellites Prognoz [52]. The longest one was observed during 26 solar rotations in the declining phase of the solar cycle 21 [53].

In addition, it turns up that not only recurrent increases of fluxes are observed, but also recurrent minima corotating along with the Sun. We named these deep decreases of particle intensity as “canyons” (due to the similarity of the spatial structure of fluxes with those in the ground canyons). Figure 17, constructed with using the data of satellite IMP-8 and of the Pioneer-11 and Voyager-1 and -2 space probes is illustrating that [54].

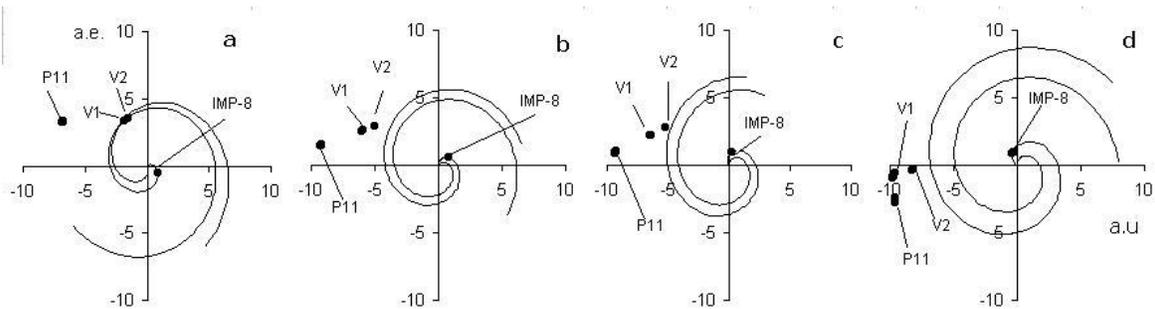


Fig. 17. Projection of the spatial structures, bordered by spirals of IMF and comprising the decreased fluxes of low energy protons ($E_p \sim 1 \text{ M\text{e}V}$), onto ecliptic plane. From left to right: 22.08. – 04.09.1978; 29.10. – 09.11.1979; 06.12. – 23.12.1979; 05.01. – 23.01.1981. The spirals were calculated according to solar wind velocities measured on IMP-8 at the beginning and at the end of intervals with “caverns” – intervals with decreased intensity of protons.

Such regions of minimum fluxes co-rotating with the Sun arise due to the fact that in the whole heliosphere there exists the constant, background fluxes of particles at some minimum level. During periods of high solar activity the background fluxes are overlapped and to observe them is possible only during quiet Sun periods, but also that is limited to the observations in some of the sectors of space surrounding the Sun.

Radiation dose from solar flares. For two powerful solar flares, namely August, 4 and 7, 1972, it was determined the radiation dose in interplanetary space using Prognoz satellite

measurement [55]. The dose out of the Earth's magnetosphere was significantly higher than that observed on Earth's orbiting satellites. This is important for the interplanetary missions as well as missions towards the Moon.

High energy gamma rays and neutrons from solar flares. IEP SAS started the satellite measurements of cosmic rays and of energetic particles in the cooperation with SINP Moscow and with other institutes in the frame of program Intercosmos in 1977. Before that period IEP SAS participated in magnetospheric energetic particle studies by data analysis since the flight of low altitude satellite IK-3 in 1971, with the instrument constructed at Charles U. Prague. This scientific direction was later continuing also experimentally, and included the measurements on Prognoz type satellites too (Intershock, Interball). It contributed to understanding the mechanisms important for identification sources, transport and losses of particles within the magnetosphere as well as in the vicinity of its boundary regions as magnetopause, bow shock as well as in the geomagnetic tail. These scientific tasks are out of scope of this review. Short summary until 2003 can be found e.g. in [56], later review is in [57].

Around 1975 there was established at IEP SAS a small experimental group developing electronics and later also complete devices for the measurement of energetic particles in the interval of energies well above those of solar wind and below the typical energies of cosmic rays. Important works in electronics were done by J. Rojko († 2011). One of the authors (KK) along with the organization of the measurements on satellites, was dealing with data analysis and its physical interpretation, together with other colleagues (L. Just † 2008, with M. Slivka and others), in cooperation with colleagues in the institutes of former USSR/Russia and in other countries. This cooperation, based on data obtained from Russian satellites, was significantly enhanced after 1989, by possibility to collaborate also with colleagues in US, west Europe, Japan etc.

First device for measurement in space with participation of IEP SAS was SK-1 developed jointly with Ioffe Physico-Technical Institute in Leningrad and launched in 1977 on IK-17 satellite. The task was to detect neutrons of solar origin in the vicinity of Earth. Although solar neutrons were not detected, this experiment measured in detail the flux of cosmic ray albedo neutrons and gamma rays at different latitudes [58]. In collaboration with SINP MSU the devices SONG were constructed (at IEP SAS the electronic box) for detection of high energy neutrons and gamma rays [59]. These devices were measuring onboard low altitude polar orbiting satellites CORONAS-I (1994) and CORONAS-F (2001 – 2005). Especially productive was CORONAS-F mission: there were detected several solar flares with high energy gamma ray emissions, its energy spectra up to > 100 MeV, as well as with the solar neutrons (e.g. [60,61]), indicating the acceleration of protons in these flares up to very high energies and providing information about the interaction of accelerated protons with residual solar atmosphere (production of neutral pions with their subsequent decay into two gamma quanta of high energies) as well as showing the timing of acceleration which is in some cases seen as a precursor before the onset of GLE (ground level events) observed by neutron monitors [62].

3. Conclusion.

In the conclusion we remark that past 100 years of cosmic ray research allowed to move substantially in understanding nature of cosmic rays, in clarifying the crucial moments of its generation, propagation in the heliosphere and in Galaxy, in understanding the role of the Sun and of planets for the formation of radiation conditions in the vicinity of the Sun. Apart from the fact that substantial progress in space physics and cosmic ray physics was achieved, there is a number of questions which are not clarified yet. Some of them are:

- Form of energy spectra of cosmic ray at very high energies $> 10^{20}$ eV;
- Change of composition with changing energy at $E > 10^{17}$ eV/nuc1;
- Determination of composition and composition of non-modulated cosmic ray with relatively low energy (< 10 GeV), i.e. in interstellar medium behind the heliospheric border;
- Influence of cosmic rays on weather and climate on Earth;
- Forecasting of the beginning of radiation hazardous flares with high flux of SCR putting obstacles for interplanetary motion of space technology and living organisms;

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