CONFERENCES AND SYMPOSIA

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75th ANNIVERSARY OF IZMIRAN

N V Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation of the Russian Academy of Sciences (IZMIRAN) yesterday, today, tomorrow

V D Kuznetsov

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Contents

Abstract. **This paper describes the basic and applied research rationale for the organization of IZMIRAN and provides insight into the 75 years of the Institute's activities and development. Historically, early magnetic measurements in Russia were developed largely to meet the Navy's navigation needs and were, more generally, stimulated by the Peter the Great decrees and by the foundation of the St. Petersburg Academy of Sciences in 1724. The paper examines the roles of the early Academicians in developing geomagnetism and making magnetic measurements a common practice in Russia. The need for stable radio communications prompted ionospheric and radio wave propagation research. The advent of the space era and the 1957–1958 International Geophysical Year Project greatly impacted the development of IZMIRAN and spurred the creation of a number of geophysical research institutes throughout the country. Currently, the research topics at IZMIRAN range widely from geomagnetism to solar-terrestrial physics to the ionosphere and radio wave propagation, and its primary application areas are the study and forecast of space weather, an increasingly important determining factor in ever-expanding ground- and space-based technologies (space navigation and communications, space activities, etc.).**

Keywords: geomagnetism, ionosphere, radio wave propagation, solar-terrestrial physics

V D Kuznetsov N V Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Russian Academy of Sciences, Kaluzhskoe shosse 4, 142190 Troitsk, Moscow, Russian Federation
Tel. +7 (495) 851 01 20. Fax +7 (495) 851 01 24
E-mail: kvd@izmiran.ru

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1. Introduction

The 75-year history of the N V Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation of the Russian Academy of Sciences (IZMIRAN in *Russ. abbr*.) has witnessed significant changes in science, the Institute has also changed, as have the scientific priorities. However, the main result of the past years is that the scientific field for which IZMIRAN was established persists and develops, producing new knowledge and being increasingly in demand.

The terrestrial magnetic field is of fundamental importance to our civilization, being part and parcel of the human environment and a kind of magnetic shield which protects all life on Earth from cosmic radiation. It forms the magnetosphere of Earth (Fig. 1) and affects the properties of ionospheric plasma, making it magnetoactive and changing the conditions of radio wave propagation. During magnetic storms, the near-Earth space (NES) is disturbed, which produces problems for satellites, radio communication, and ground-based power systems. Nowadays, NES perturbations also affect the signals of the modern navigation systems GPS (Global Positioning System) and GLONASS (Global Navigation Satellite System), as well as everything related to them. The interrelation of effects on the Sun and in the terrestrial magnetosphere and ionosphere, as well as their influence on the milieu of human habitation and activity, impart a complex nature to the study of the terrestrial magnetic field, which includes all factors responsible for changes, both from above — from the Sun, and from below — from Earth's interior.

2. From the history of geomagnetism

It is not precisely known in the history of terrestrial magnetism when the magnetic compass was invented; however, there is documentary evidence of its use for orientation in the north–south direction even in the first

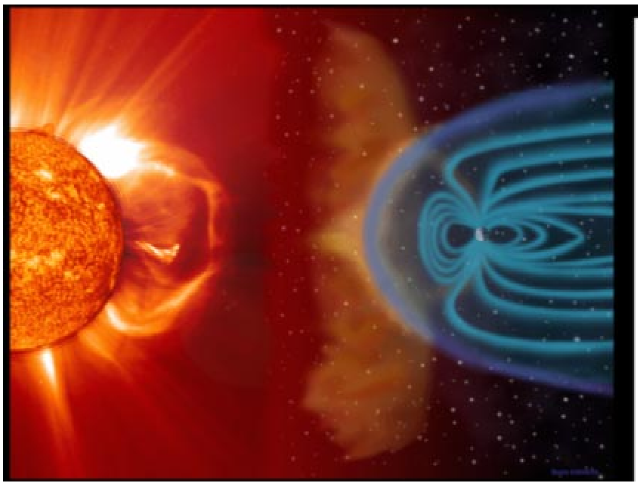

Figure 1. Magnetosphere of Earth formed in the flow of the solar wind past the dipole terrestrial magnetic field.

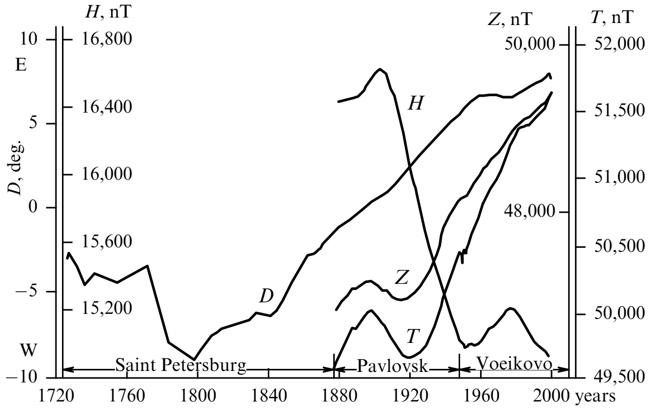

Figure 2. Plots of the secular run of the elements of the geomagnetic field in the cities of Saint Petersburg (1724–1878), Pavlovsk (1878–1941), and Voeikovo (1948–2000) constructed in the Saint Petersburg's Branch of IZMIRAN. Arrows indicate the times of observation transfers to new sites [1]. *D* — magnetic declination, *H*, *Z*, respectively, the horizontal and vertical components of the magnetic field *T*.

centuries of the Common Era. The beginning of geomagnetism studies dates back to the 15th century, and it was related to the development of seafaring and navigation [1]. The first measurements of terrestrial magnetic field intensity with the simplest compass were made in Italy in 1436.

A major impetus to the development of geomagnetic science was made by the discovery of magnetic declination (the angle between the directions to the geographic and magnetic poles) during Columbus's four expeditions from Europe to America (1492–1504). The magnetic declination was found to depend on the ship's geographical position, and today we know that it also varies with time at each point due to the secular drift of the geomagnetic field itself. Interestingly, when residing in a line connecting the magnetic and geographic poles, the direction to the geographic pole is strictly opposite to the magnetic arrow direction.

The first determination of magnetic declination on Russia's territory was made in 1556 by the English traveler Steven Borough in Pechora; more recently, the magnetic declination was determined by English researchers. Coast-dwelling navigators were some of the first to notice that the 'matka' (the word they used in reference to a compass) played pranks during auroras. We now know why. The idea that the operation of a compass is related to the terrestrial magnetic field was presumably expressed by the English scientist William Gilbert in his book, *De Magnete* (*About the Magnet*), published in London in 1600. This work originated our notions of the existence of a common geomagnetic field.

In Russia, a start in studies of the geomagnetic field was made at the time of Peter the Great (1672–1725), which was related to the development of Russia's fleet and sea navigation needs. According to a decree enacted by Peter I, the duty of measuring the magnetic declination when sailing was imposed on all ship captains and commanders. Peter I also wrote the first instructions for the navy "On the practical application and handling of compasses." The establishment of the Petersburg Academy of Sciences at Peter's behest by a 1724 Decree of the Governing Senate became an important step in the development of geomagnetic research in Russia. Even at the first grand public Academy meeting on 27 December 1725, the Academy placed the science of terrestrial magnetism into the category of those with the highest importance.

Systematic observations of magnetic declination, which commenced in 1726 according to Peter's decree, have not been interrupted and are now one of the longest European series of observations (Fig. 2). Curve *D* in Fig. 2 is the secular run of terrestrial magnetic declination in St. Petersburg for almost 300 years. The change of field direction over this period amounts to about 16°, which is quite substantial, and therefore the field variations are to be continually measured and taken into consideration. Nowadays, observations of magnetic declination continue at the Voeikovo Observatory, which is a part of the St. Petersburg Branch of IZMIRAN.

In the Petersburg Academy of Sciences, interest in geomagnetism was so keen that many outstanding Russian academicians worked, to one extent or other, in this area. Academician Leonard Euler (1707–1783) was one of the first to derive formulas which permitted determining the locations of magnetic poles and later on calculating the strengths of the magnetic field at any point on the globe, although the accuracy of calculations by these formulas turned out not to be high enough for practical applications. Euler disputed Halley's hypothesis of the existence of two magnets inside Earth. Inside the globe, he believed, there was a single magnet displaced relative to Earth's center, and the "amount of magnetic matter residing in Earth's interior was subject to appreciable changes, resulting in temporal variations of declination." In 1741, Academician Daniel Bernoulli was awarded a prize from the French Academy of Sciences for developing the theory of an inclinator — an instrument for measuring the terrestrial magnetic declination, which was a topical problem at that time. In 1759, Academician Franz Aepinus wrote a treatise, *Tentamen Theoriae Electricitatis et Magnetismi* (*An Attempt at a Theory of Electricity and Magnetism*), which had a profound impact on the subsequent development of the science of magnetism, at least in Russia. He supported Euler's idea of a single magnet. Aepinus wrote: "...the core itself is subject to slow variations as regards its shape and the distribution of magnetic matter over it."

A significant contribution to the development of the doctrine of geomagnetism was made by Mikhail Vasil'evich Lomonosov in his work, *Rassuzhdenie o Bol'shei Tochnosti*

Morskogo Puti (*Reasoning about the Higher Accuracy of Shipping Routes*). He made quite a modern assumption that the globe consisted of variously magnetized tiny particles. In the aggregate, they make up a nonuniformly magnetized globe, which accounts for the difference in magnetic declination in different parts of the globe. This was a step forward relative to W Gilbert's notions, which considered the terrestrial magnetic field to be the field of one magnet with two poles, and thereby forestalled C F Gauss's idea of an arbitrary magnetization of Earth globe. M V Lomonosov also promoted the solution of practical problems of measuring the elements of terrestrial magnetism. An expedition was dispatched in accordance with his project; one of the tasks set before the expedition was making measurements of the magnetic field.

In 1835, a Corresponding Member of the Petersburg Academy of Sciences Ivan Mikhailovich Simonov elaborated a new theory of geomagnetism in his work, *Opyt Matematicheskoi Teorii Zemnogo Magnetizma* (*Experience on Mathematical Theory of Terrestrial Magnetism*) [2, 3]. He showed that Earth's magnetic field due to the combined effect of magnetic particles residing inside the globe would coincide with the field of a dipole, assuming a uniform distribution of the particles. I M Simonov's work came out even before the publication of C F Gauss's fundamental work [4] (translated into Russian as *Obshchaya Teoriya Zemnogo Magnetizma — General Theory of Geomagnetism*), and the dipole potential as a function of latitude and longitude given by Simonov turned out to be identical to the first expansion term of the potential introduced by Gauss.

A thorough and comprehensive study of terrestrial magnetism at a qualitatively new scientific level is associated with two classical studies by the great mathematician, Academician Carl Friedrich Gauss (Fig. 3). In the first of them, dated 1832, he proposed a new method of measuring the horizontal component of magnetic field induction, which immediately permitted an improvement in measurement accuracy, and proposed a design of the instrument for these purposes. In 1837, Gauss invented a unipolar magnetometer, and in 1838 a bifilar one. In the second study [4], dated 1838, Gauss developed the mathematical theory of the potential, which represented the terrestrial magnetic field **B** in the form of an expansion of terrestrial magnetic potential V in an infinite series of spherical functions:

$$V(r,\theta,\varphi) = R\sum_{n=1}^{\infty}\sum_{m=0}^{n}\left(\frac{R}{r}\right)^{n+1} \times \left(g_n^m \cos m\varphi + h_n^m \sin m\varphi\right) P_n^m(\cos\theta)\,, \quad \mathbf{B} = -\nabla V\,,$$

where R is the standard radius of Earth (6371.2 km), r is the distance from Earth's center, g_n^m are the Gauss coefficients, and P_n^m are spherical functions (associated Legendre polynomials).

The fitting of Gauss coefficients in his expansion that best describe magnetometric data of the network of magnetic observatories and satellites still underlies modern models of the geomagnetic field — the so-called International Geomagnetic Reference Field, which is updated every five years.

The Magnetic Union scientific society (Göttingen), launched by C F Gauss and W Weber in 1834, set itself the task of studying terrestrial magnetism on the whole planet. Gauss and other scientists succeeded in attracting the attention of the governments of different countries to the study of the terrestrial magnetic field and to the organization of new and development of existing observatories in Germany, France, England, and Russia.

In 1829, the Petersburg Academy of Sciences came to a decision to construct the first magnetic observatories in Russia, the credit going to Alexander von Humboldt and a member of the Petersburg Academy of Sciences, professor at Kazan' University, A Ya Kupffer (Fig. 4). By that time, approximate maps of magnetic fields had already been

Figure 3. Great mathematician C F Gauss (1977–1855), who contributed significantly to the theory of geomagnetism.

Figure 4. Academician of the Petersburg Academy of Sciences Adolf Yakovlevich Kupffer (1799–1866).

plotted for the entire Russian territory, and a start was made on the development of projects for the systematic magnetic survey of the territory of the Russian Empire. In Petersburg, the first regular magnetic observations were made by A Ya Kupffer in the physics office of the Academy of Sciences in 1829.

3. IZMIRAN's prehistory

In 1830, A Ya Kupffer built a magnetic pavilion, which was referred to as a Magnetic Observatory, behind the northern wall of the Petropavlovsk Fortress in St. Petersburg. This first Petersburg magnetic observatory may be said to have become the first step in the setting up of IZMIRAN. The plan of deploying a set of magnetic observatories was approved, and magnetic measurements were further elaborated. Later on, owing to the interference introduced by trams, precision magnetic measurements in the center of St. Petersburg became impossible, and the magnetic observatories were moved, initially to the Vasil'evskii Island to the so-called Normal Observatory of the Main Physical Observatory (MPO), and then to the town of Pavlovsk (Slutsk after the revolution) near St. Petersburg. The Pavlovsk Observatory was the best one in the world: scientists would come there from abroad to train, gain experience, and calibrate instruments, and it played the role of a base observatory in the teaching of personnel and making reference instruments.

In 1892, on Academician F A Bredikhin's suggestion, the first simultaneous observations of magnetic storms and solar phenomena were carried out on the basis of the Pavlovsk Magnetic Observatory and the Central Astronomical Observatory at Pulkovo. Subsequently, such observations, despite the fact that they were interrupted more than once, eventually led to the establishment of the Solar Survey as a necessary element for studying the solar-terrestrial relationship and cause-and-effect relations in the Sun–Earth system.

The year 1896 saw the publication of the first issue of the quarterly international journal *Terrestrial Magnetism*, which was renamed *Terrestrial Magnetism and Atmospheric Electricity* in 1899. In 1938, S Chapman suggested replacing the term 'terrestrial magnetism' with the term 'geomagnetism'.

In 1916, the post of MPO director was filled, for a short period, by Academician A N Krylov, who published the book *O Zemnom Magnetizme* (*On Terrestrial Magnetism*) [5] in 1922. In 1924, the MPO in Pavlovsk was renamed the Main Geophysical Observatory (MGO), and the Geomagnetic Division was organized at Petersburg as a part of it, with its supervision entrusted to N V Roze. The major task of the Geomagnetic Division was preparing for the General Magnetic Survey of the country, interrupted by the World War I.

During the succeeding years, the MGO underwent several reorganizations to become in 1930 an All-Union Research Institute with specialized institutes organized within it, including the Institute of Terrestrial Magnetism and Atmospheric Electricity (ITMAE) (1931). Subsequently, it was several times renamed and reorganized, with the result that the initially united magnetic divisions of the institute — the Geomagnetic Expeditions Group (formerly the General Magnetic Survey Bureau), Atmospheric Electricity Sector, Terrestrial Magnetism Group, Slutsk Magnetic Observatory — all taken separately became centrally subordinate to the MGO. N V Pushkov was appointed supervisor of the Slutsk (Pavlovsk) Magnetic Observatory.

In 1938, a conference, held on a regular basis in the Central Slutsk Observatory, of the supervisors of all magnetic observatories, whose number amounted to 17 by that time, adopted a recommendation to apply, in the name of the Central Administration of the Hydrometeorological Service, to the USSR Council of People's Commissars (Sovnarkom) with a suggestion to organize, on the basis of the Slutsk Observatory and the Geomagnetic Expeditions Group, the Institute of Terrestrial Magnetism as a unified scientific and methodical institution on terrestrial magnetism and solar survey.

4. Establishment and development of IZMIRAN

On 11 October 1939, the Sovnarkom passed a resolution to organize the Scientific-Research Institute of Terrestrial Magnetizm (NIIZM (in *Russ. abbr.*)) under the aegis of the Main Directorate of the Hydrometeorological Service using the Slutsk (Pavlovsk) Magnetic Observatory as the base, with its location in the town of Slutsk. The Magnetic Survey and Cartography Group in Leningrad also became a part of NIIZM. Candidate of physicomathematical sciences, N V Pushkov, was appointed director of the NIIZM.

The main tasks of the Institute were the following: comprehensive complex studies of the phenomena of terrestrial magnetism, terrestrial currents, auroras, and the ionosphere; improvement of the methods and instruments required for studying these phenomena; scientific and methodical supervision over the Magnetic Service of the USSR; provision of data on terrestrial magnetism for the country's economy, cultural development, and defense. The scientific programs of the Institute also comprised observations of the ionosphere and magnetic ionospheric disturbances, short-term forecasts of the state of the magnetic field, and solar observations. This was all due to the need of providing reliable radio communications and predict the conditions for radio wave propagation in the ionosphere in relation to solar and geomagnetic activities. By the beginning of 1940, NIIZM staff numbered slightly more than one hundred people. The Institute's staff comprised 45 scientists, including two professors, eight candidates of sciences, and 34 junior scientific associates.

The founder and the first director of the Institute Nikolai Vasil'evich Pushkov (Fig. 5) was a student of the Physicomathematical Department of Moscow State University (beginning in 1926) and subsequently became one of the first postgraduate students of the Department of Magnetometry (1930) of the Physicomathematical Department of Leningrad State University, chaired by N V Roze. In 1934, N V Pushkov defended his candidate's thesis, entitled "Teorii Kosmicheskogo Magnetizma" ("Space Magnetism Theories") and became a senior scientific associate of the Slutsk Magnetic Observatory and later (in 1937) its director. He made a decisive contribution to the organization of the Institute, the formation of its subject area and staff, and equipping the Institute with scientific instrumentation. N V Pushkov — a laureate of the Lenin Prize, an honored worker in science and technology of the Russian Soviet Federative Socialist Republic (RSFSR), a holder of three Orders of Labor Red Banner and an Order of Honor, one of the founders of Soviet geophysics and world solar-terrestrial physics — was in charge of the Institute for 30 years. In 2004, the Presidium of the RAS conferred the name of N V Pushkov on the Institute. His name was also given to a street in the town of

Figure 5. Nikolai Vasil'evich Pushkov (1903–1981), the organizer and the first Director of IZMIRAN.

Troitsk (Pushkovs street, after the father and son) and the first school in the town (presently a gymnasium); there are memorial plaques on the institute building and in the town, which were placed in memory of N V Pushkov as the founder of IZMIRAN and the science campus.

One and a half years after the Institute was set up, the Great Patriotic war broke out, and NIIZM became a paramilitary institution of the Red Army. The Institute was evacuated from blockaded Leningrad to the Urals, to the site of a magnetic observatory in the village of Kosulino near Sverdlovsk (Ekaterinburg). There, the staff members undertook ionospheric and solar observations and set up a solar and ionospheric forecast service, made maps of magnetic declination along an important air route across the Chukotka peninsula, and prepared long-term ionosphere state forecasts for the needs of the Red Army.

E I Mogilevskii and N P Ben'kova, who worked in the institute for many years, made a major contribution to the development of the solar and ionospheric services in the country. They arrived in Krasnaya Pakhra (now Troitsk — *Translator's comment*) in December 1944 among the first staff members of the future Institute which first established the town as a city of science.

A small group of staff members stayed in Leningrad. Scientific associates N N Trubyachinskii, A Ya Bezginskii, P E Fedulov, B P Veinberg, and others perished during the blockade; N V Roze was groundlessly repressed and also perished. The Pavlovsk Observatory was completely ruined by the war.

In 1944, the Institute was transferred to Krasnaya Pakhra and moved into an unfinished building of the Moscow Geophysical Observatory. The first scientific 'landing' (1944) originated the scientific settlement and subsequently the scientific center in Troitsk. (In connection with this event and the 75th anniversary of the Institute, a decision was made to lay a memorial stone at the center of Troitsk.) A start was made on the construction of the main building and others of the Institute and the Magnetic Observatory; the staff members would construct the first Finnish dwelling houses. Many staff members lived in the main building of the Institute.

The magnetic survey and cartography groups returned to Leningrad from evacuation to become the foundation of the Leningrad (presently St. Petersburg) Branch of IZMIRAN, organized in 1946. Since 1946, a new Magnetic Observatory and an Ionospheric Station commenced their operation at the Leningrad Branch in Voeikovo. A Design Bureau was organized in the Institute and work on pilot instrument-making was undertaken. In particular, quartz magnetometers were made for the Geophysics Department in the new building of Moscow State University.

The second decade of the Institute's activities was full of important events, which made for its further development and consolidation. There is no escape from mentioning the campaign, which was commenced in the late 1940s-early 1950s, aimed at oppressing physicists as some continuation of the oppression of geneticists. This campaign did not pass by N V Pushkov, who experienced, together with Academician E K Fedorov and other physicists, the so-called court of honor. They were charged, in particular, with the continuation of scientific contacts with foreign researchers, which were, of course, necessary during World War II. This was overcome, and N V Pushkov even managed, against all odds, to employ the physicists Ya L Al'pert and Ya I Likhter, who had been dismissed from the P N Lebedev Physical Institute (LPI), as well as nuclear physicists from amongst the MSU graduates, who organized in the Institute the Department of Cosmic Ray Variations, which was headed by L I Dorman for many years.

In 1951, the Murmansk Branch of the Institute was set up for comprehensive studies of magnetic ionospheric effects, which are most intense in high latitudes, as well as auroras. In 1953, the Institute received a nonmagnetic schooner *Zarya* (Fig. 6) for measuring magnetic fields in sea water. Its yearly expeditions permitted obtaining a wealth of data for plotting magnetic maps; features of global geomagnetic field distribu-

Figure 6. Nonmagnetic schooner *Zarya* (1953–1988).

tion and ionospheric processes were studied, and previously unknown magnetic anomalies were discovered. Unique data were accumulated over the 35 years of the schooner's operation.

In 1956, the Institute was turned over to the USSR Ministry of Communications in connection with a significant increase of the ionosphere and radio wave propagation investigations in its scientific projects. A new name was attached to the Institute: Research Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation (NIZMIR in *Russ. abbr*.). The number of research areas in radio communication and radio wave propagation increased, and a start was made on Antarctic research expeditions.

The International Geophysical Year (IGY) in 1957, a major international project, became a turning point for the development of the Institute, which turned from a more or less specialized institute into an academic one. Under the leadership of the Institute, extensive research was started in solar-terrestrial physics with the participation of many institutes of the Academy of Sciences and state's Ministry institutions. New scientific centers concerned with solar-terrestrial physics research were set up all across the country: Siberian Branch of IZMIRAN in Irkutsk (presently, the Institute of Solar-Terrestrial Physics of the Siberian Branch of the RAS), the Polar Geophysical Institute in Murmansk based on the Murmansk Division of NIIZM, and the Institute of Cosmophysical Research and Aeronomy in Yakutsk.

On N V Pushkov's and Yu D Kalinin's initiative, an academic journal, *Geomagnetizm i Aeronomiya* (*Geomagnetism and Aeronomy*) was set up in 1960, which became the leading world periodical on geophysics and solar-terrestrial physics. One of the two IGY World Data Centers — MTsD-B2 — was organized at the Institute, which accumulated the materials of numerous observations from around the world to be used for scientific research. In 1971, this center was turned over to the Interdepartmental Geophysical Committee.

With the launch of the first artificial Earth satellite (AES) and the onset of the space era, the Institute turned out to be at the threshold of a new scientific area, which we now refer to as basic space research [6]. Immediately after the launch of the first satellite, President of the USSR Academy of Sciences M V Keldysh asked V A Kotel'nikov to consider the question of whether it was possible to obtain some scientific data using the satellite. V A Kotel'nikov addressed himself to IZMIRAN to Ya L Al'pert, who did this by using the satellite's radio beacon signal for studying the outer layers of the ionosphere in radio occultation observations as the satellite rises above and sets below the horizon. This was the first-ever scientific space experiment [7–9].

It is also pertinent to note that even prior to the launch of the first satellite, A V Gurevich [10], then a staff member at IZMIRAN, performed the first theoretical calculations of the interaction of a metal satellite body with the rarefied ionospheric plasma. He obtained density and electric potential distributions in the neighborhood of the satellite. These calculations were of significance for formulating and interpreting different satellite-borne experiments and underlay the more detailed subsequent experiments concerning this problem [11–13].

The world's first magnetic experiment in space was carried out with the third AES in 1958. It involved the first comparison of space measurements with the data of geomagnetic field models, as well as an analysis of the field of the East-Siberian magnetic anomaly. Data were obtained concerning the possibility of exploiting the geomagnetic field for determining the orientation of a space vehicle [14, 15]. For these investigations, N V Pushkov and the head of the Institute's magnetic laboratory Sh Sh Dolginov, together with S N Vernov and A E Chudakov of MSU, were awarded the Lenin Prize, the first in the area of space research. In the subsequent years, satellite magnetic measurements were carried out in the terrestrial magnetosphere, in interplanetary space, and in the vicinity of the Moon, Venus, and Mars, and data were obtained about the magnetic fields of these planets.

In 1959, the Institute was turned over under the aegis of the USSR Academy of Sciences and obtained its present-day name IZMIRAN. The justification for this was the Institute's active work during the IGY, its important role in space research, the significant contribution to the general line of research, and the high scientific potential of the Institute. At the 1960 annual meeting of the Academy of Sciences, its President, A N Nesmeyanov, said in his opening speech that the Academy had been replenished with one more scientific institution — the Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation — with its 'dowry', a Lenin Prize.

IZMIRAN played a major part in the deployment of a network of complex magnetic ionospheric stations in different regions of the country and in the elaboration of unified recommendations for running the corresponding measurements. By the 1960s, 37 magnetic observatories and 35 ionospheric stations were operating in the USSR. V N Bobrov designed a universal quartz magnetosensitive element (sensor) with high metrological parameters. V N Bobrov and N D Kulikov, a quartz glass blower, fabricated a large series of quartz magnetometric sensors and instruments based on this measuring unit. Many domestic magnetic observatories, as well as those in more than 20 countries in the world, were equipped with these devices. The first domestic serial production of an automatic ionospheric station (AIS), which worked for more than 50 years in several complex observatories in the country and several foreign observatories, aboard research vessels of the USSR Academy of Sciences, and in the Vostok Station in the Antarctic, was made at the Institute in those days.

Apart from space research, undoubtedly among the Institute's scientific priorities is the determination of the shape of the aurora domain, as carried out by Ya I Fel'dshtein, of the so-called aurora oval [16], or the Fel'dshtein oval (Figs 7 and 8), which gained worldwide recognition.

In the 1960s, the Institute appreciably enlarged the scale of research both on geomagnetic fields and on near-Earth space; in addition, the scientific-organizational and material-technical basis of the Institute became firmer. A Special Design Bureau of physical instruments (SDBPI) was set up, in which a series of unique instruments was made — magnetic variation stations, ionoprobes, and several of the world's largest extra-eclipsing coronagraphs designed by G M Nikol'skii, which were successfully used for solar observations in domestic and foreign observatories.

Organized in 1965 near the town of Ladushkin in the Kaliningrad region was the Kaliningrad Complex Magneto-Ionospheric Observatory (KCMIO), which is the most western point of domestic observations. Today, KCMIO is part of the Kaliningrad Branch of IZMIRAN.

Figure 7. Yakov Isaakovich Fel'dshtein.

In 1966, on N V Pushkov's initiative and under his chairmanship a Scientific Council on the Solar-Terrestrial Relationship (the Sun–Earth Council) was organized at the General Physics and Astronomy Division of the USSR Academy of Sciences, which operates at the present time.

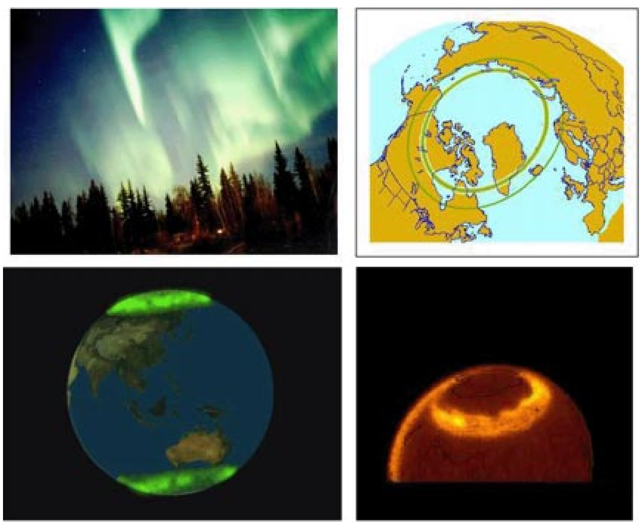

Figure 8. Aurora oval, which was discovered for the first time by Ya I Fel'dshtein.

The task of the Sun–Earth Council is the coordination of work on solar-terrestrial physics in our country and the realization of international cooperation. At that time, E I Mogilevskii developed a solar vector magnetograph, which permitted the world's first simultaneous measurements of all components of the magnetic field in active solar regions, and a neutron supermonitor — a detector with enhanced sensitivity for recording cosmic ray variations — was put into operation. The entire Soviet network of cosmic ray stations was equipped with such monitors, and new stations were added to the network. In the 1960s, a field magnetic variation station (IZMIRAN-4) was developed at the Institute, which found wide use both in the USSR and abroad: about 400 of these stations were placed at many points around the globe.

For IZMIRAN, the 1960s–1970s and the subsequent years were the 'Big Bang' years as regards space science (Fig. 9). The Institute participated in many space projects and carried out investigations of the ionosphere, the magnetic fields of Earth, the Moon, and the planets, and a solar research. As a result of these investigations, local ionospheric properties were studied, a global magnetic survey was conducted covering 75% of the terrestrial surface, a contribution was made to the construction of the first analytical International Geomagnetic Field Model, and numerous other results were produced [6, 17].

With the beginning of manned space flights (1961), the Institute participated in providing the radiation safety of the cosmonauts proceeding from solar observations, by forecasting solar flares and their impacts on the near-Earth space. The Institute's participation in the development and implementation of complex scientific programs became a characteristic feature of its activities. In the 1960s, IZMIRAN collaborated actively in the International Quiet Sun Year and International Active Sun Year programs.

In 1969, N V Pushkov appealed to the Presidium of the USSR Academy of Sciences to accept his resignation from his directorship for health reasons, and the position of IZMIRAN's director was filled by an MSU professor, V V Migulin (Fig. 10), a direct pupil of L I Mandelstam and N D Papaleksi, a well-known radiophysicist, and subsequently a Corresponding Member and Academician of the USSR AS [18–20]. By that time, the Institute's staff had increased nine-fold in number, there were approximately 900 staff members in IZMIRAN and 360 staff members in the IZMIRAN SDBPI.

With V V Migulin's arrival, an impetus was given to radiophysical ionospheric research with the aid of modern facilities developed at the Institute [Soika-600 Digital Ionospheric Station, Bazis Ionospheric Station (ionoprobe), Multifrequency Radiophysical Facility, Experimental Facility for Multifrequency Phase Ionosphere Probing, etc.], which permitted performing detailed investigations of ionospheric processes, radio wave propagation conditions, and the effects of the interaction of high-power radio-frequency radiation from heating facilities with the ionospheric plasma.

In the 1970s, the Institute participated widely in active experiments in space with the use of rockets, which were implemented under the auspices of the Space Research Institute (IKI in *Russ. abbr*.), RAS. In these experiments, a study was undertaken of the physical effects that take place when electron beams and plasma jets are injected into the ionosphere from on board a rocket, and an artificial aurora was observed [21]. During that period, IZMIRAN took also part in the international programs International Investiga-

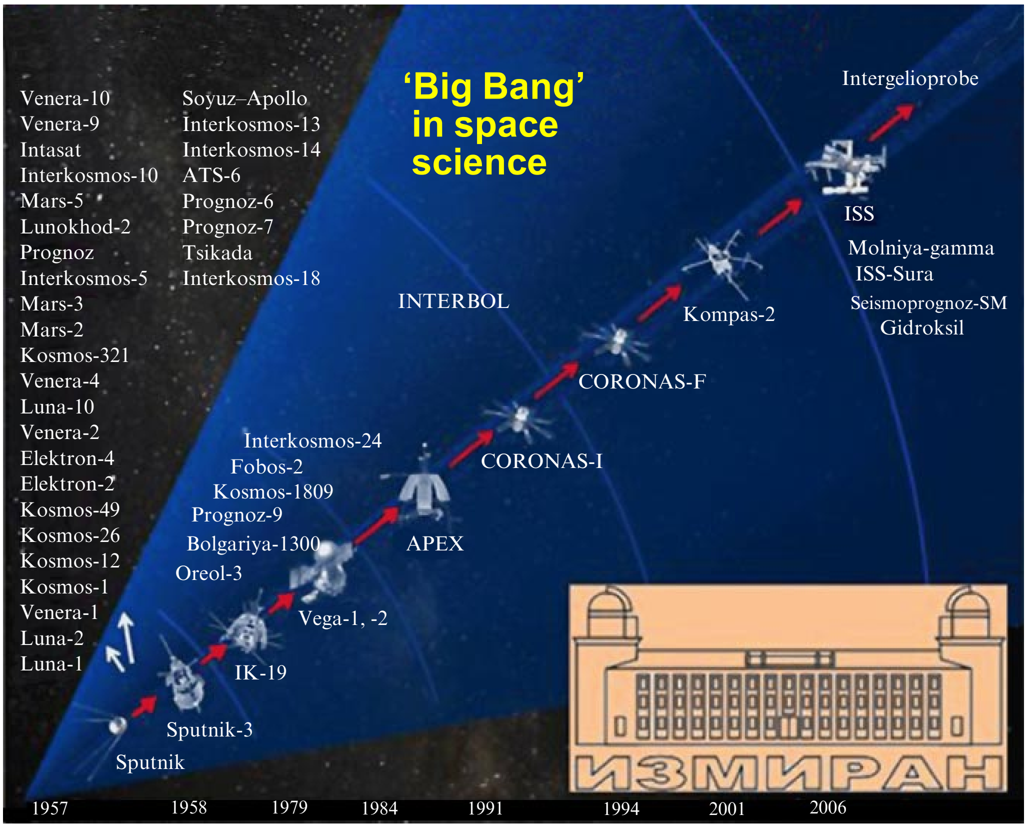

Figure 9. IZMIRAN's space research.

tions of the Magnetosphere and Solar Maximum Year. During the flight of the *Soyuz* and *Apollo* mission, G M Nikol'skii performed successfully the first exoatmospheric experiment involving the observation of an artificial solar eclipse, in which it was possible to observe the solar corona far away from the Sun and examine the corona brightness distribution along the ecliptic at a long distance from the Sun.

Figure 10. Vladimir Vasil'evich Migulin (1911–2002).

In IZMIRAN's space investigations, mention should be made of the most significant domestic space project in ionospheric research — Interkosmos-19 (1979–1982) — with a topside sounding of the ionosphere. The investigations were executed over a vast territory of the globe and a wealth of data was obtained. This data set is still being processed and analyzed at the present time; earthquake effects in the ionosphere were also discovered [22].

In the 1980s, ionospheric research was continued with several other satellites. During these years, the Institute also participated in Vega-1 and Vega-2 space experiments on the investigation of Halley's comet. In these experiments, original data on the electromagnetic wave processes in the near-Earth region were gathered and measurements were made of the magnetic field near the comet [23]. Also, a unique series of magnetic field measurements in the vicinity of Mars was made from aboard the Fobos-2 space vehicle [24].

A Theoretical Department has been working in the Institute since 1969. Initially, it was supervised by a well-known theorist, Professor V I Karpman. Over the years, the Institute's theorists have studied nonlinear wave phenomena in space plasma physics, collective effects in the generation and propagation of radio waves in the ionosphere, plasma effects emerging in the execution of active experiments, and other phenomena in related research areas, including astrophysics and nuclear physics [25, 26].

In 1989, Professor V N Oraevskii became IZMIRAN's Director (Fig. 11). Implemented under his supervision was the Active Plasma Experiments in Space (APEX) project involving the injection of charged particle beams into the magneto-

Figure 11. Viktor Nikolaevich Oraevskii (1935–2006).

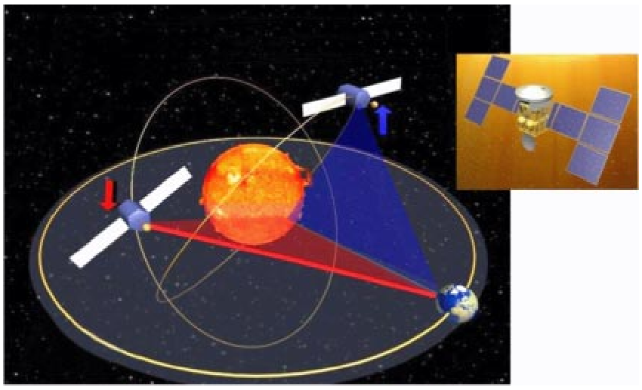

Figure 12. Intergeliozond project intended for investigating the Sun and the inner heliosphere, with the participation of IKI RAS, IZMIRAN, FIAN, the A F Ioffe Physicotechnical Institute RAS, the D V Skobeltsyn Institute of Nuclear Physics MSU, the National Research Nuclear University MEPhI, and the Radiophysical Research Institute.

spheric plasma [27]. He also started, jointly with I I Sobel'man of the LPI, the CORONAS [CORONAS — Kompleksnye ORbital'nye Okolozemnye Nablyudeniya Aktivnosti Solntsa (Complex orbital near-Earth observations of solar activity)] program concerned with solar research and the effects of solar activity on the near-Earth space [28]. IZMIRAN scientists were awarded a State Prize and a prize from the Russian Federation Government for the implementation of the APEX and CORONAS-F projects.

In recent years, IZMIRAN, in collaboration with other partners, performed a series of experiments with a Sura heating facility with the use of optical observations from aboard the Russian Segment of the International Space Station (ISS). These experiments point to the possibility of initiating a magnetic substorm under radio wave heating of the ionosphere and thereby of controling the characteristics of the geophysical medium [29]. A number of other experiments aboard the ISS have been prepared and implemented.

Today, continuous observations of the geomagnetic field and ionosphere are pursued at the Institute's laboratories in Moscow (Troitsk), near St. Petersburg, in Kaliningrad, and in Vladikavkaz, from an observation site in Karpagory in Arkhangel'sk region, and at cosmic ray stations. These observations are integrated into the Russian and international observational network and are employed for carrying out research and for studying and monitoring space weather.

Unique balloon-based geomagnetic investigations make use of the gradient technique of measurements along a long route — from Kamchatka to the Urals. As a result, magnetic anomalies were studied and valuable data were obtained for the improvement of modern models of the terrestrial magnetic field [30].

The motions of terrestrial magnetic poles, which are of significance by themselves and for magnetic navigation and terrestrial climate studies, are continuously monitored and analyzed by magnetologists from the Institute with the use of all available magnetic data [31]. The polarity reversal of the terrestrial magnetic field (whereby the northern and southern magnetic poles change places), which has occurred many times in the past, also occupies the attention of IZMIRAN's magnetologists today. As before, the data on magnetic declination are nowadays requested by many organizations in the country (aviation, defense and cadastral services, geodesy and cartography, oil companies, etc.). A general magnetic survey with the participation of IZMIRAN and other organizations is planned in the framework of the Geophysical Monitoring of the Territory of the Russian Federation program, beginning in 2016.

In the area of space research, the Institute is participating in the framework of a broad cooperation program in the preparation of a complex of scientific instrumentation for the Interhelioprobe space project to investigate the Sun and solar sources of space weather [32]. The Institute began work on this priority project in 1995. This project plans for the first time to execute continuous out-of-the ecliptic observations of the solar polar regions for studying the solar dynamo and the solar cycle, as well as to carry out several unique scientific experiments (Fig. 12).

IZMIRAN is engaged in broad international cooperation with different scientific organizations and unions, and it participates in the implementation of several international programs and projects. When V V Migulin became Director of the Institute and was familiarizing himself with its research areas, he said jokingly: "IZMIRAN is like a department store: it has everything." Astronomy and astrophysics, solar-terrestrial physics and geophysics, plasma physics and radiophysics, high-energy and cosmic ray physics — these are the realms of science that are represented, to one extent or another, in the research activities of the Institute. And so the width of the circle of cooperation is also large: International Association of Geomagnetism and Aeronomy (IAGA), Committee on Space Research (COSPAR), Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), International Astronomical Union (IAU), International Union of Radio Science (URSI), and other international organizations.

Today, the topicality of the research areas related to IZMIRAN's activities is increasing; they are becoming progressively more demanded from the practical standpoint as well. This is due to the expansion of ground-based and space technologies and infrastructures, which are becoming vulnerable to the factors of space weather owing to their large scale [33], while IZMIRAN is concerned with the science of space weather, which must be studied, monitored, and predicted. Today, the task of the Institute is to realize these opportunities for maintaining and developing the Institute and for continuing research work.

The Space Weather Forecasting Center set up at the Institute delivers information to organizations of the space-related industry — to the Space Flight Control Center and to space launching sites, to medical institutions, oil and gas companies, and the media. Information about space weather forecasts is transmitted by Central TV every day. The progress in the study of solar activity and the terrestrial magnetic field is used for developing forecasting methods, improving prediction reliability, and eventually mitigating the effect of solar activity and space weather factors on the ground and space activities.

Today, the traditional lines of the scientific activities of the Institute — terrestrial and planetary magnetism, the ionosphere and radio wave propagation, solar-terrestrial physics, and scientific instrument making — are being filled with new substances, leaning upon new experimental data of ground- and space-based observations, their modern development trends being permanently analyzed by the Institute's staff members. The Institute possesses a high scientific potential and vast experience for solving the tasks set before it. However, the problem of involving additional young staff remains urgent.

Prepared for celebrating the 75th anniversary of the Institute was the book, *Elektromagnitnye i Plazmennye Protsessy ot Nedr Solntsa do Nedr Zemli* (*Electromagnetic and Plasma Processes From the Solar Interior to Earth's Interior*) based on the results of research over many years, which was a continuation of the book published 25 years ago when celebrating the 50th anniversary of the Institute [34].

IZMIRAN was the founder of the scientific settlement which is now the town of Troitsk, a city of science, and this role, now honorary, of the Institute in originating the city of science is part and parcel of the history of Troitsk itself. Many parcels of land and buildings of the Institute were turned over to the town and other institutes for development. Today, as earlier in the history of magnetic measurements, the Institute is facing the problem of moving the magnetic observatory, which bears the name Moscow Observatory, to a more distant place, which is void of trams and other sources of interference for magnetic measurements.

5. Conclusions

Over the 75 years of its activity, IZMIRAN has passed through several development stages to go from a highly specialized institute to a modern research institute of the Russian Academy of Sciences. To a large extent, this was due to the demand for and topicality of IZMIRAN's research area, its active and diversified scientific activity for many years, its contribution to the incipient space research and the general research areas, and the high scientific potential of the Institute.

In the area of geomagnetism, the Institute developed a wide variety of magnetometric instruments for studying the terrestrial magnetic field and its variations, and performed the first-ever magnetic measurements in space. The Institute participated actively in the deployment of a domestic network of magnetic ionospheric observatories, including Arctic and Antarctic stations. IZMIRAN has participated directly in the organization of other institutes with related research profiles.

The Institute has performed complex experimental investigations of the ionosphere and radio wave propagation conditions with the exploitation of developed radiophysical facilities, and constructed theoretical models which permitted understanding the basic physical features of radio wave–ionosphere interactions of significance for a number of practical applications. In a series of space ionospheric projects ranging from the first AES to problem-oriented satellites (Interkosmos-19), studies have been done of global and local ionospheric properties, the ionospheric effects of lithospherical processes, and anthropogenic activity.

In the area of solar-terrestrial physics, the Institute has designed and made coronagraphs, telescopes, magnetographs, radio spectrographs, and cosmic ray detectors, which permitted studying active processes on the Sun, their effect on the terrestrial magnetic field, and the state of the ionosphere. IZMIRAN was the leading organization in the implementation of the first Russian complex solar projects (CORONAS-I, CORONAS-F), which laid a firm basis for institutes' cooperation in this area. A large-scale solar space project, Interhelioprobe, which was developed at IZMIRAN, is now in the preparatory stage with the participation of a broad range of Russian and foreign institutes. The results of research in this area enjoy practical applications in the study and prediction of space weather, which exerts progressively greater influence on ground- and space-based infrastructure of society as its scale increases.

Like many other scientific institutes, today IZMIRAN continues to exist and work in the framework of the Federal Agency of Scientific Organizations, while remaining inseparably tied to the Russian Academy of Sciences.

References

1. Raspopov O M et al. *Istoriya Nauk o Zemle* **2** (2) 18 (2009)
2. Simonoff I M *J. Reine Angew. Math.* **16** 197 (1837)
3. Simonoff I M "O zemnom magnetizme" ("About terrestrial magnetism"), in Gauss C F *Izbrannye Trudy po Zemnomy Magnetizmu* (Selected Works on Terrestrial Magnetism) (Moscow: Izd. AN SSSR, 1952) p. 245
4. Gauss C F *Resultate aus den Beobachtung des magnetischen Vereins im Jahre 1838* Bd. 1 (Göttingen: Dieterichsche Buchhandlung, 1839)
5. Krylov A N *O Zemnom Magnetizme* (About Terrestrial Magnetism) (Petrograd: Red.-izd. otd. Morsk. kom., 1922)
6. Kuznetsov V D *Phys. Usp.* **53** 528 (2010); *Usp. Fiz. Nauk* **180** 554 (2010)
7. Al'pert Ya L *Usp. Fiz. Nauk* **64** 3 (1958)
8. Al'pert Ya L et al. *Usp. Fiz. Nauk* **65** 161 (1958)
9. Alpert Y *Making Waves*: *Stories from My Life* (New Haven: Yale Univ. Press, 2000)
10. Gurevich A V *Tr. Inst. Zemn. Magn. Ionosf. Rasprostr. Radiovoln* **17** (27) 173 (1960)
11. Gurevich A V *Iskusstv. Sputniki Zemli* (7) 101 (1961)
12. Al'pert Ya L, Gurevich A V, Pitaevskii L P *Sov. Phys. Usp.* **6** 13 (1963); *Usp. Fiz. Nauk* **79** 23 (1963)
13. Al'pert Ya L, Gurevich A V, Pitaevskii L P *Space Physics with Artificial Satellites* (New York: Consultants Bureau, 1965); Translated from Russian: *Iskusstvennye Sputniki v Razrezhennoi Plazme* (Moscow: Nauka, 1964)
14. Dolginov Sh Sh, Zhuzgov L N, Pushkov N V *Iskusstv. Sputniki Zemli* (2) 50 (1958)
15. Dolginov Sh Sh, Pushkov N V, in *Uspekhi SSSR v Issledovanii Kosmicheskogo Prostranstva* (USSR Advances in Space Research) (Ed.-in-Chief A A Blagonravov) (Moscow: Nauka, 1968) p. 173
16. Fel'dshtein Ya I, in *Elektromagnitnye i Plazmennye Protsessy ot Solntsa do Yadra Zemli* (Electromagnetic and Plasma Processes

from the Sun to the Core of the Earth) (Exec. Ed. V V Migulin) (Moscow: Nauka, 1989) p. 108
17. Kuznetsov V D *Phys. Usp.* **53** 947 (2010); *Usp. Fiz. Nauk* **180** 988 (2010)
18. Gulyaev Yu V *Phys. Usp.* **55** 301 (2012); *Usp. Fiz. Nauk* **182** 323 (2012)
19. Vyatchanin S P *Phys. Usp.* **55** 302 (2012); *Usp. Fiz. Nauk* **182** 324 (2012)
20. Kuznetsov V D *Phys. Usp.* **55** 305 (2012); *Usp. Fiz. Nauk* **182** 327 (2012)
21. Oraevskii V N, Mishin E V, Ruzhin Yu Ya, in *Elektromagnitnye i Plazmennye Protsessy ot Solntsa do Yadra Zemli* (Electromagnetic and Plasma Processes from the Sun to the Core of the Earth) (Exec. Ed. V V Migulin) (Moscow: Nauka, 1989) p. 77
22. Karpachev A T, in *Entsiklopediya Nizkotemperaturnoi Plazmy* (Encyclopedia of Low Temperature Plasma) Vol. I–3 *Ionosfernaya Plazma* (Ionospheric Plasma) Pt. 1 (Eds V D Kuznetsov, Yu Ya Ruzhin) (Moscow: Yanus-K, 2008) p. 381
23. Riedler W et al. *Nature* **321** 288 (1986)
24. Riedler W et al. *Nature* **341** 604 (1989)
25. Karpman V I, in *Elektromagnitnye i Plazmennye Protsessy ot Solntsa do Yadra Zemli* (Electromagnetic and Plasma Processes from the Sun to the Core of the Earth) (Exec. Ed. V V Migulin) (Moscow: Nauka, 1989) p. 162
26. Kuznetsov V D *Geomagn. Aeronom.* **49** 691 (2009); *Geomagn. Aeronomiya* **49** 723 (2009)
27. Oraevsky V N, Tríska P *Adv. Space Res.* **13** (10) 103 (1993)
28. Kuznetsov V D (Ed.) *The CORONAS-F Space Mission: Key Results for Solar Terrestrial Physics* (New York: Springer, 2014); Translated from Russian: *Solnechno-Zemnaya Fizika: Rezul'taty Eksperimentov na Sputnike CORONAS-F* (Moscow: Fizmatlit, 2009) p. 34
29. Ruzhin Yu Ya et al. *Geomagn. Aeronom.* **53** 43 (2013); *Geomagn. Aeronomiya* **53** (1) 46 (2013)
30. Tsvetkov Yu P et al. *Dokl. Earth. Sci.* **436** 117 (2011); *Dokl. Ross. Akad. Nauk* **436** 262 (2011)
31. Zvereva T I *Geomagn. Aeronom.* **52** 261 (2012); *Geomagn. Aeronomiya* **52** (2) 278 (2012)
32. Kuznetsov V D, in *Proekt Intergeliozond. Trudy Rabochego Soveshchaniya, Tarusa, 11–13 Maya 2011 g.* (Intergeliozond Project. Workshop Proc., Tarusa 11 – 13 May 2011) (Ed. V D Kuznetsov) (Moscow: IZMIRAN, 2012) p. 5
33. Bothmer V, Daglis I A *Space Weather: Physics and Effects* (Berlin: Springer, 2007)
34. Migulin V V (Exec. Ed.) *Elektromagnitnye i Plazmennye Protsessy ot Solntsa do Yadra Zemli* (Electromagnetic and Plasma Processes from the Sun to the Core of the Earth) (Moscow: Nauka, 1989)