Similarly to the way in which not every complex function can be a wavefunction, since it has to satisfy the Schrödinger equation, not every field $a^2(\mathbf{r}, t)$ and $\mathbf{V}(\mathbf{r}, t)$ can represent a quasifield: they have to correspond to some wavefunction.

2.6 If we substitute the wavefunction $\psi(\mathbf{r}, t) = a(\mathbf{r}, t) \exp\big(\mathrm{i}\beta(\mathbf{r}, t)\big)$ into Schrödinger equation (1.3) and take into account relation (2.3) for the quasifield velocity, then expressions (1.6) and (1.7) for the real and imaginary parts of the Schrödinger equation acquire a simple physical meaning. Indeed, with account for Eqn (2.3), relation (1.6) becomes

$$\frac{\partial a^2}{\partial t} = -\nabla(a^2\mathbf{V}) \,, \tag{2.8}$$

and relation (1.7), if one takes the gradients of both its sides, changes to

$$-m\,\frac{\partial \mathbf{V}}{\partial t} = -\frac{\hbar^2}{2m}\,\nabla\,\frac{\nabla^2 a}{a} + \frac{m}{2}\,\nabla V^2 + \nabla U \,. \tag{2.9}$$

Equation (2.8) is equivalent to equation (2.2) and indicates that the quasifield cannot appear or disappear but can only be displaced. Equation (2.9), taking into account Eqns (1.10) and (2.3), will be equivalent to Eqn (2.5), i.e., to the statement that acceleration of the quasifield elements is equal to the sum of the forces, the external one and the quasifield one, divided by the particle mass. Thus, the Schrödinger equation for the quasifield corresponds to the gas dynamics equation, the only difference being that the force of the quasifield self-action, denoted here by $\mathbf{F}_{\mathrm{q}}$, is essentially different from the analogous force in gas dynamics.

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Vladimir Aleksandrovich Kotel'nikov and Solar System studies

L M Zelenyi, N A Armand

1. Introduction

In biographically portraying the work of Academician Vladimir Aleksandrovich Kotel'nikov, one usually describes his outstanding work devoted to the fundamentals of the communication theory (the famous sampling theorem, the potential noise immunity theory, theorems in cryptography theory). His role in Soviet space programs is described to a lesser extent. Meanwhile, the contribution of Vladimir Aleksandrovich and colleagues from the organizations founded and headed by him [the Special Design Bureau of Moscow Power Engineering Institute (OKB MEI in *Russ. abbr*.) and the Institute of Radioengineering and Electronics of the Russian Academy of Sciences (IRE RAS)] to this field is also very significant. Another side of his 'space' activity is related to his positions as the Vice President of the USSR Academy of Sciences and the Head of the Intercosmos Council.

In this short report we shall briefly describe the main stages of V A Kotel'nikov's activity, who was an outstanding scientist, engineer, politician, and scientific manager.

2. V A Kotel'nikov and space radar

The development of space radar was motivated by quite practical needs. In the 1960s, the state of space facilities in the USSR and USA allowed scientists and engineers to plan scientific space missions in order to explore nearby planets: Venus and Mars. To ensure the approach of spacecraft to these planets at a distance of several hundred kilometers, one needed to know their position relative to Earth with a good accuracy. Previous astronomical observations of Solar System's bodies located them precisely only relative to each other, while the absolute values of the mutual distances had been known very crudely from the space navigation point of view, which required high accuracy to handle the spacecraft.

All distances between planets are conveniently expressed through the astronomical unit (a.u.), which is equal to the mean distance from Earth to the Sun and is estimated to be around 150 mln km. Astronomical observations had determined this value to an accuracy of about 10,000 km. This means that the distance, for example, to Venus had been known to an accuracy of several thousand kilometers. Clearly, this accuracy could not be considered as satisfactory.

Radio ranging provided the possibility of measuring the distance between Earth and a nearby planet with the required accuracy. To measure the distance with a one-kilometer accuracy, it is sufficient to send radio pulses with a duration of approximately 6 μs. The question is how powerful these pulses should be for the reflected signal to exceed the noise level in a ground-based detector. Considering that in radio ranging 'the inverse fourth power distance law' operates and interplanetary distances are at best several dozen million kilometers, it is easy to understand that antennas with an area of several thousand square meters and transmitters with a power of several dozen kilowatts are required for successful radio ranging of planets. This was very expensive and accessible only for countries with highly developed industry. So it was quite natural that planetary radar started developing in the USA, the USSR and partially in the UK.

At that time, the Remote Space Communication Center (RSCC) was constructed near the city of Eupatoria (Crimea) in the USSR. The center was designed for communications primarily with spacecraft to be sent to Venus and Mars. For this purpose, three ADU-1000 antennas (Fig. 1) were constructed: one for signal transmission, and the other two for signal reception. The radio transmitter with a power of about 10 kW operated at a wavelength of 40 cm. These characteristics fit planetary radar requirements, so the RSCC was chosen to perform the experiment.

Advances in radar facilities (increase in transmitter power and detector sensitivity, development of digital frequency-linear signal modulation, etc.) allowed a very precise measurement of the astronomical unit: $1\ \mathrm{AU} = 149{,}597{,}867 \pm 0.9$ km. Such an accuracy required knowing very precisely the speed of light, since in radio ranging one directly measures the time of radio pulse propagation, and the distance between space bodies is obtained by multiplying the delay time by the speed of light. For this reason, the XVIth General Assembly of the International Astronomical Union (1967), by analyzing the results of experiments carried out in the USSR and USA, adopted the value of $1\ \mathrm{AU} = 149{,}597{,}870 \pm 2$ km for the assumed speed of light $c = 299{,}792{,}558 \pm 1.2\ \mathrm{m\ s^{-1}}$. Such a high accuracy in determining the astronomical unit has provided successful flights of spacecrafts for planetary studies and exploration of the interplanetary space in the Solar System. Moreover, such an

Figure 1. The ADU-1000 antenna.

V A Kotel'nikov with colleagues from the Institute of Radioengineering and Electronics, who participated in Venus radar ranging. (From left to right: A M Shakhovskii, V A Kotel'nikov, O N Rzhiga, V M Dubrovin.)

accuracy required the usage of general theory of relativity for the correct description of motion of the Solar System planets. This problem was tackled, in particular, thanks to efforts of specialists from the Central Research Institute of Mechanical Engineering (TsNIIMASh in *Russ. abbr.*), the Institute of Applied Mathematics (IAM) RAS, and IRE RAS.

In addition to determining the astronomical unit by means of planetary radio ranging, other interesting results have also been obtained. Let us discuss the most important result in our opinion, which is related to the determination of the rotational period of Venus. It was very difficult to determine this period by optical methods since Venus is covered by a thick cloudy layer. Radar methods afforded the possibility of determining the planet's rotational period, since the rotation produces spectral broadening of the radio signal reflected from the planetary surface. As a result, the rotational period of Venus was found to be $T = 243.04$ days, which was about the same value as obtained in the USA. The International Astronomical Union adopted this period to be 243.01 days. It is interesting to note that in contrast to other planets, Venus has the opposite rotation with respect to the sense of orbital revolution around the Sun. Interestingly, the measured value is very close to the period of synodical resonance at which only one side of Venus should have been observed from the Earth at periods of the bottom conjugation.

The experience of planetary radar accumulated by IRE RAS was broadened by pupils of Vladimir Aleksandrovich during radio ranging of small bodies of the Solar System. These bodies having small sizes, the bistatic ranging method turned out to be the most convenient, in which the illumination was performed by one antenna and the reception of the reflected signal was made by another antenna. When the radars are located sufficiently far away from each other, it is possible to emit quite a long-duration signal and coherently accumulate the reflected signal with the receiving antenna. This required international collaboration, in which financial consideration also played its role. The Russian side, more precisely, the Russian – Ukrainian side, used the TNA-2500 antenna (Fig. 2) constructed at CRSC (in the city of Eupatoria) as far back as in the Soviet times. Foreign collaborators used antennas at Effelsberg (Bonn), at Goldstone (USA), at Kashima (Japan), and at Medicina (Italy). The following asteroids were radio ranged: 4179 Tautatis, 6479 Golevka, and 1998 WT24. The analysis of the received signals allowed estimation of the rotational velocity of these objects, their sizes, the scattering capability, etc. Figure 3 demonstrates the possibilities of spectral analysis for reconstructing the surface relief of the WT24 asteroid. When reconstructing the relief, the permanent rotation of the asteroid is essential, so that radio waves scattered by different points of its surface experience different Doppler shifts. The total spectrum of the scattered signal is similar to the spectra shown in the left panel of Fig. 3 for two orthogonal circular polarizations obtained for different aspect angles of the asteroid.

Figure 2. The TNA-2500 antenna.

Space planetary radar was further developed with the launch of the Venera-15 and Venera-16 missions that had onboard radars with a synthesized aperture. As mentioned

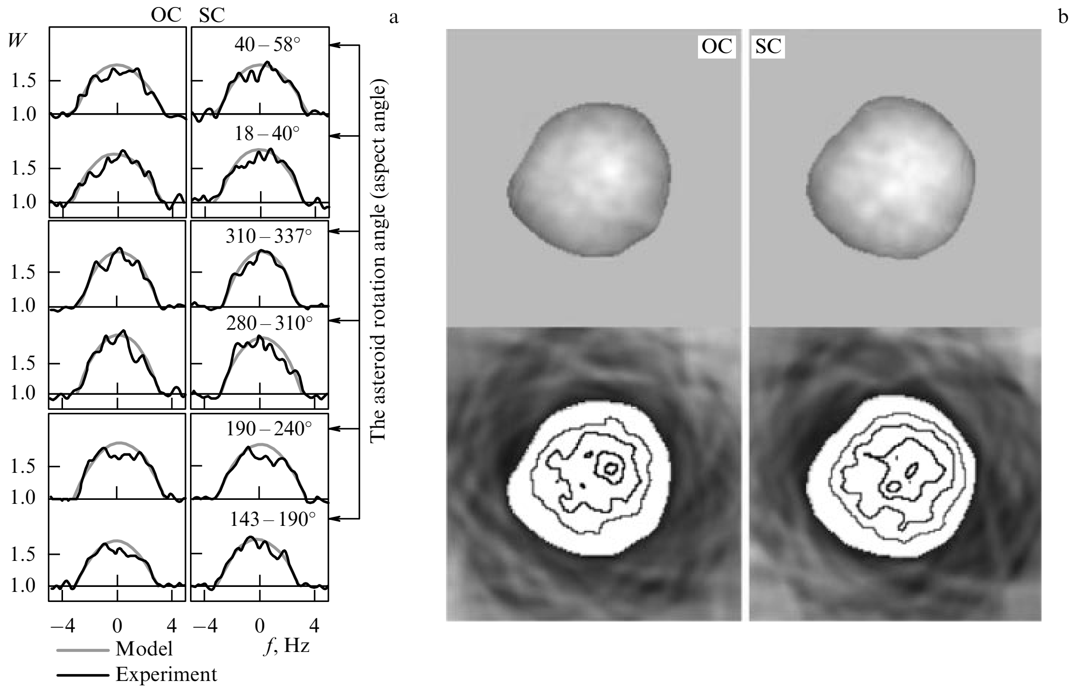

Figure 3. (a) Comparison of the observed and model power spectra from a rough ellipsoid observed at different aspects. (b) Radio image of the asteroid WT24 in two polarizations.

above, the surface of Venus is permanently covered by a thick cloudy layer, so it is impossible to capture its image in the optical range even from the planet's artificial satellite. It could be done only by a planetary lander, which was accomplished in 1975 by the Venera-9 and Venera-10 spacecraft. Here one should take into account that the landers operated under a temperature of about 700 K and a pressure of about 100 atmospheres. But the area of the surface observed by these modules was too small to make meaningful geological conclusions; this requires imaging large areas, which can be done only from satellites of the planet.

This task was successfully realized in 1983 by the Venera-15 and Venera-16 missions. Radars with a synthesized aperture on these satellites (Fig. 4) allowed taking images of the planetary surface from a distance of 1000 km with a spatial resolution of 1 km.

V A Kotel'nikov was the informal leader of this project and played the decisive role in coordinating the activity of IRE RAS, OKB MEI, Lavochkin Research and Production Association, and several other industrial and academic organizations. The imaging of 115 mln km^2 of the north Venerian hemisphere (25% of the planetary surface) was done. An example of one of such radar images is shown in Fig. 5.

The radar imaging of a planet fully covered with clouds was an outstanding scientific achievement that greatly contributed to world science. The analysis of these images has been invaluable for the development of comparative planetology.

The realization of this project also contributed to the development of the radar image processing technique. In particular, for the first time in the Soviet Union the procedure for obtaining digital images was carried out. This experience was later applied in designing the software for processing radar images taken by radars with synthesized aperture onboard the Almaz orbital complex, designed for performing radio cartography of the surface of the Earth with a spatial resolution of 10 m.

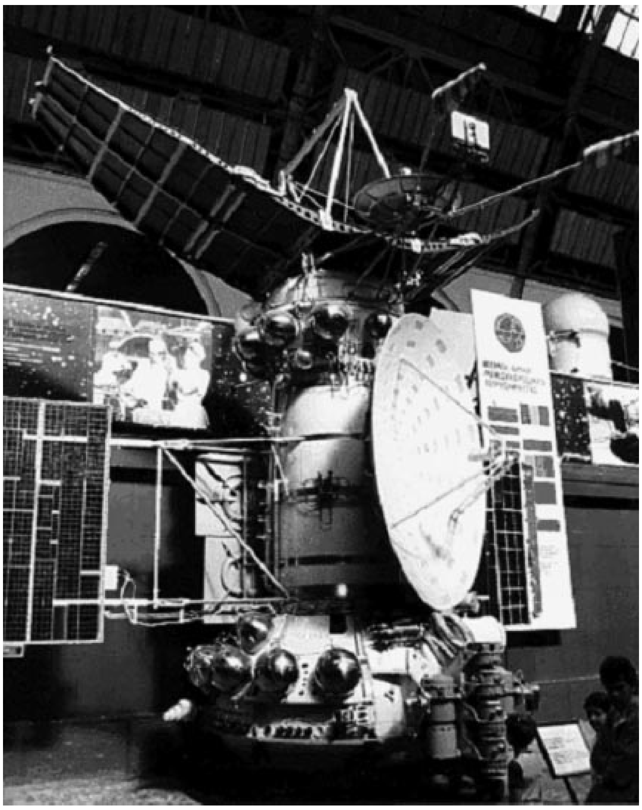

Figure 4. The Venera-15 spacecraft.

Prospects for Solar System radio ranging research. Radar studies of the planets of the Solar System initiated under the leadership of V A Kotel'nikov was continued in IRE RAS

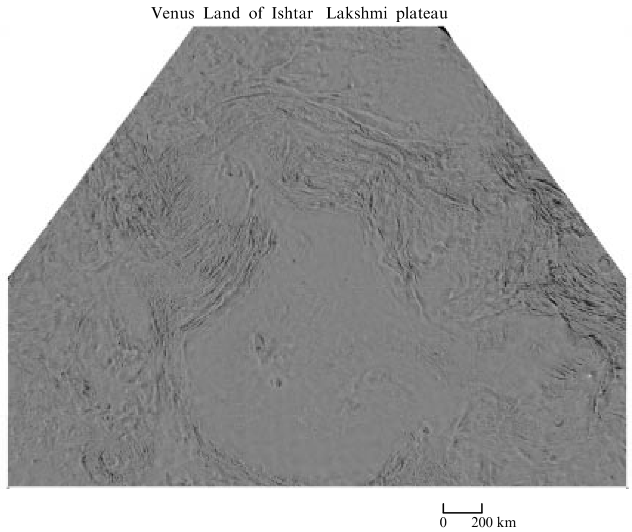

Figure 5. A portion of a radar image of Venus.

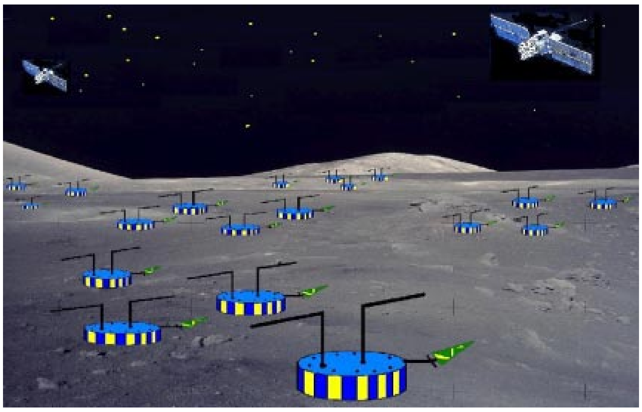

Figure 6. Low-frequency radio astronomy on the lunar surface.

programs aimed at the subsurface radar sounding of the planets realized from their artificial satellites. Currently, these studies are being carried out at the stage of processing the data obtained with the MARSIS radar (Mars Advanced Radar for Subsurface and Ionosphere Sounding) onboard the Mars-Express spacecraft launched by the European Space Agency (ESA).

Radar studies in the framework of the Phobos-Ground project are in prospect. It is planned to install onboard a module landing on the surface of Phobos a subsurface-sounding radar operating at a carrying frequency of 150 MHz with a bandwidth of 50 MHz. It is assumed that this module will probe the subsurface structure of Phobos up to depths of at least 100 m with a resolution of 2 m.

The possibility of subsurface radio ranging of the Moon is also being discussed (Fig. 6). The principal tasks include:

- studies of the subsurface layer structure up to a depth of several kilometers;
- studies of the dielectric properties of the lunar ground;
- discovery and identification of large inclusions of various rocks;
- localization of ground sites with enhanced passability;
- studies of large-scale lunar roughness;
- improvement of the lunar surface topography.

To address these issues, it is required to design a multi-frequency radar with final specifications according to the detailed Russian program of lunar studies, which is now under formation.

In a long-term outlook, radar imaging of the icy sheath of the Jovian satellite Europa (with the estimated bulk from several kilometers up to 100 km) is feasible. If this ice is freshwater, it is virtually transparent in a wide radio frequency range. So, the dielectric properties of the icy sheath are essential for the choice of radar frequencies. For example, due to large scattering on the highly rough ice, too short radio waves (e.g., of decimeter wavelengths) cannot be used. Decameter waves cannot also be chosen because of the strong noise generated by synchrotron radiation in the Jovian radiation belts. Apparently, using meter wavelengths could be the compromise. Time will show what the choice of the Russian space mission towards Europa will be. However, the strong level of radioactivity around Jupiter is the most severe problem. This places high demands on the safety of both the space platform and its service and scientific payload. This also leads to a significant shortening of the entire lifetime of the mission.

3. V A Kotel'nikov and the Intercosmos program

Space research and explorations require international collaboration. It should be recalled that the first artificial satellite of the Earth (ASE) was launched during the International Geophysical Year (1957 – 1958) — a wide program of terrestrial studies, in which scientific institutes from 66 countries were involved.

The First Secretary of the Central Committee of the Communist Party of the Soviet Union (CC CPSU) at that time, Nikita Khrushchev, very rapidly (only in a few days after the launch of the first ASE) became aware of a huge propaganda potential of space research due to the frequently hidden military implications of civil explorations.

It was also obvious that science, including rapidly developing space research, could become a powerful addition to economic successes, and a means of strengthening the relations (both ideological and personal) between peoples from socialist countries. Nuclear physics and space research seemed to be the most important fields of science in the second half of the 20th century. Quite rapidly, without the usual red tape, the Joint Institute for Nuclear Research in Dubna and the Council for International Collaboration for Space Research and Exploration of the USSR Academy of Sciences (the Intercosmos Council, for brevity) were founded under the leadership of the Vice President of the USSR AS, Academician B N Petrov.

Space physics, space meteorology, the physics and techniques of remote radio communications and television, space biology and medicine, and distant Earth sounding (DES) were to become the principal fields of scientific collaboration in space research.[1] The joint construction and launching of artificial satellites and the design of equipment and scientific payload were also being discussed.

By April 1967, the detailed program of joint space research has been elaborated. The program involved institutions from Bulgaria, Hungary, Vietnam, the GDR, Cuba, Mongolia, Poland, Romania, the Soviet Union, and Czechoslovakia. The scientific potentials of these countries were very different, and the motto of Intercosmos, "Socialism is the

[1] DES was added to the program in 1973.

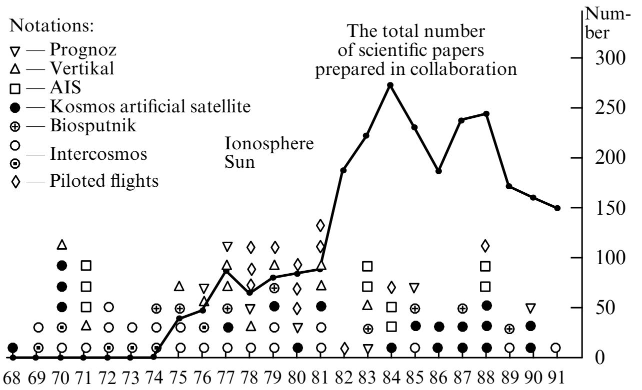

Figure 7. History of the Intercosmos space launches.

launch pad for space flights,'' can be remembered now both ironically and with a certain nostalgia. But that was our past, and the above words were to a large extent correct — exactly at that time the space industry was founded in the countries participating in the Intercosmos program.

We stress from the very beginning that the Soviet Union provided other countries participating in the Intercosmos program with free access to all Soviet technology, unique at that time, including spacecraft, rockets, launch sites and ground measurement stations, and equipment for preparing, launching, and controling the space flights. Another feature of the Intercosmos program was that each country proposed its own research program and could participate in partners' experiments which were of interest to it, in designing the scientific payload, and, frequently, in the elaboration of service systems to be installed onboard satellites; the results of joint research were equally shared among the participants.

At the annual meetings the leaders of national coordinating bodies took principal decisions, issued recommendations concerning different practical problems, and discussed the prospects of cooperation developing in different fields. In 1980, the outstanding Soviet scientist and science administrator V A Kotel'nikov became the head of the Soviet national coordination body and Head of the Intercosmos Council. Under his leadership in the 1980s, the program matured and the most significant scientific research was carried out (Fig. 7).

The first step in pursuing the Intercosmos program was the realization of a space experiment on complex studies of the upper terrestrial atmosphere and the nature of aurora, conducted onboard the Kosmos-261 satellite in December 1968.

The complex experiment was prepared jointly by research institutes and geophysical observatories from the countries participating in the Intercosmos program. Synchronous ground-based observations of the atmosphere and troposphere had been organized and the obtained space and ground-based data were jointly analyzed. Several new results were obtained, in particular, the diffusion of the auroral zone toward the equator from the oval of discrete auroras was discovered.

Simultaneously, new satellites for further research were being elaborated. In the technical documentation of the Yuzhnoe Design Bureau in Dnepropetrovsk, these satellites were named Intercosmos-1, Intercosmos-2, etc. And although the Kosmos-261 satellite (by the way, the first practical work of plasmophysicists from the Space Research Institute of the USSR AS that was founded shortly before) officially opened the Intercosmos program, it was decided not to change its name in order not to confuse drafts and documentation.

On October 14, 1969, the Kosmos-1 launch vehicle (the converted version of the R-12 ballistic missile) put into orbit the spacecraft D-UZ-IK-1, called by the press Intercosmos-1. The launch took place in the Kapustin Yar launch site (about twenty kilometers from Volgograd) in the presence of scientists from nine countries participating in the program.

In the following years, in the framework of the Intercosmos program 24 other satellites of the Intercosmos series were launched, 11 high-altitude Vertikal rockets and several hundred meteorological rockets of different modifications. In total, from 1967 to the beginning of the 1990s, taking into account scientific and social-economic spacecraft (biosatellites, Meteor, Meteor-Priroda, Molniya, etc.), automatic interplanetary stations (AISs) Luna, Venera, Vega, etc., piloted Soyuz spacecraft and orbital stations (Salyut, Mir series), the well-developed missile and space infrastructure of the USSR in collaboration with participating countries of the Intercosmos program allowed around 100 spacecraft with various destinations (excluding meteorockets and high-altitude balloons) to be launched.

Most Intercosmos satellites (22 of 25) were manufactured in the Yuzhnoe Design Bureau under the leadership of V M Kovtunenko. In order to design and organize in a short period of time the industrial production of a large number of spacecraft of different destinations, nonstandard decisions were required. The principle of base platform unification (i.e., the usage of a unique frame structure, the standard set of service units, a common scheme of payload control, a common system of electric power supply) turned out to be the most acceptable. For the first time in the world, in essence, line production of satellites was organized. The unification allowed not only shortening the manufacturing time, but also significantly decreasing the production costs.

Starting from Intercosmos-15, a more complex and heavier platform — the automatic unified orbital station (AUOS) — was utilized. To put this platform into orbit, a more powerful launch vehicle was required — the conversion variant of the R-14 ballistic missile. During the flight of Intercosmos-15 new onboard systems were also tested, including the united telemetric system (UTMS) elaborated jointly by specialists from Hungary, the GDR, Poland, the USSR, and Czechoslovakia. This system allowed the telemetry from satellites to be received by ground stations located in the territory of the participating countries. The UTMS was also installed onboard the next Intercosmos-18 and Intercosmos-19 satellites.

The Intercosmos satellites, depending on their destination and scientific goals, can be subdivided into several groups, including:

• Solar series: Intercosmos-1 (1969), Intercosmos-4 (1970), Intercosmos-7 (1972), Intercosmos-9 (Copernicus-500) (1973), Intercosmos-11 (1974), and Intercosmos-16 (1976). These satellites were designed to study ultraviolet and X-ray solar radiation and sporadic solar radio emission;

• ionospheric series: Intercosmos-2 (1968), Intercosmos-8 (1972), Intercosmos-12 (1974), Intercosmos-19 (1979), Intercosmos-22 (Bulgaria-1300) (1981);

• magnetospheric series: Intercosmos-3 (1970), Intercosmos-5 (1971), Intercosmos-6 (1972), Intercosmos-10 (1973), Intercosmos-13 (1975), Intercosmos-14 (1975), Intercos-

Figure 8. The Intercosmos-20 spacecraft.

mos-17 (1977), Intercosmos-18 (1978). These satellites were designed to study processes in the upper terrestrial atmosphere, low-frequency electromagnetic radiation, the dynamics of terrestrial radiation belts, ultrahigh-energy cosmic radiation, and electromagnetic coupling between the magnetosphere and ionosphere. Intercosmos-6 satellite was equipped with a lander with a scientific payload.

The small Czechoslovakian satellite Magion was separated from Intercosmos-18. The joint flight of two spacecraft was aimed at studying the spatial structure of low-frequency electromagnetic fields in near-Earth space. Coordinated observations were carried out from ground-based ionospheric and solar observatories of the countries participating in the program.

Testing of an experimental system of data acquisition from ground-based and naval measuring facilities (buoys) and its retransmission through the central station to customers was started onboard the Intercosmos-20 and Intercosmos-21 spacecraft (Fig. 8). For the first time, the multizone spectrophotometer MKS was installed onboard these satellites. This device successfully combined the scientific methods developed by Soviet scientists and the technical facilities produced by specialists from the GDR. The updated variant of this instrument later operated onboard the Salyut-7 piloted orbital station.

Intercosmos-22, devoted to the 1300th anniversary of the Bulgarian state foundation, was constructed by Bulgarian and Soviet specialists. The scientific payload included a multichannel optical electrophotometer, a high-energy ion and electron analyzer, an ion drift meter, an ultraviolet photometer, units to measure electron temperature and number density, a unit to measure the ionic component of plasma, a proton counter, an ultrahigh frequency radiometer operating at a wavelength of 4 cm, and some other devices. The Meteor-2 spacecraft was chosen as the base platform for this satellite.

In April 1985, Intercosmos-23 (also known as Intershock) was launched which, like Intercosmos-1, -4, -7, -9, -11, and -16, was designed to study solar–terrestrial relations. In this case, studies were carried out on a new basis, from the Prognoz automatic station (Fig. 9). The orbit of this satellite was elongated toward the Sun and reached several hundred thousand kilometers in the apogee. This allowed probing regions outside terrestrial magnetic field during most of the orbital period. The launch was aimed at studying the structure of the interplanetary and near-Earth shocks produced by solar wind interaction with the Earth's magnetosphere. Such shocks have an unusual structure, since particle collisions (which lead to braking the hypersound fluxes in ordinary gases) are nearly absent in extremely rarefied space plasma, and the necessary dissipation is provided by collective wave processes. The station was equipped with devices elaborated by scientists from the USSR and Czechoslovakia. Another feature of Intercosmos-23 (Prognoz-10) (Fig. 10) was the presence of various rapidly operating diagnostic tools, including a multichannel plasma spectrometer and a complex of devices measuring plasma waves, as well as an onboard computer controlling the experiment and providing automatic measurement of the shock front crossing time,

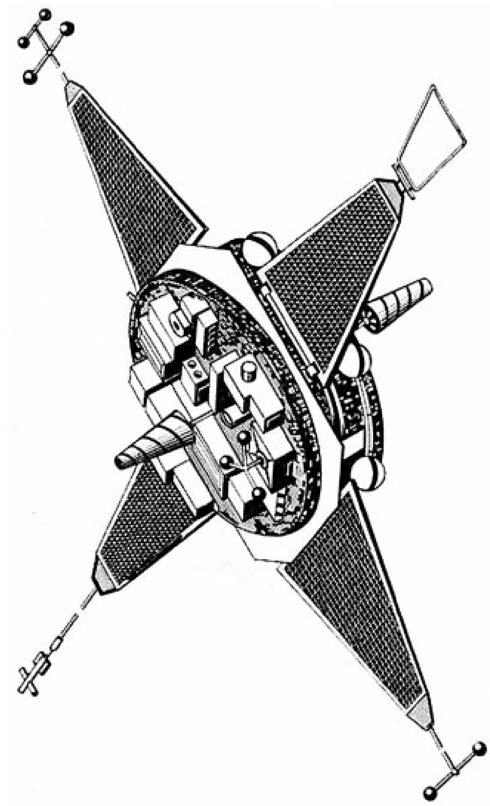

Figure 9. The base platform — the Prognoz station.

Figure 10. Intercosmos-23 (Prognoz-10).

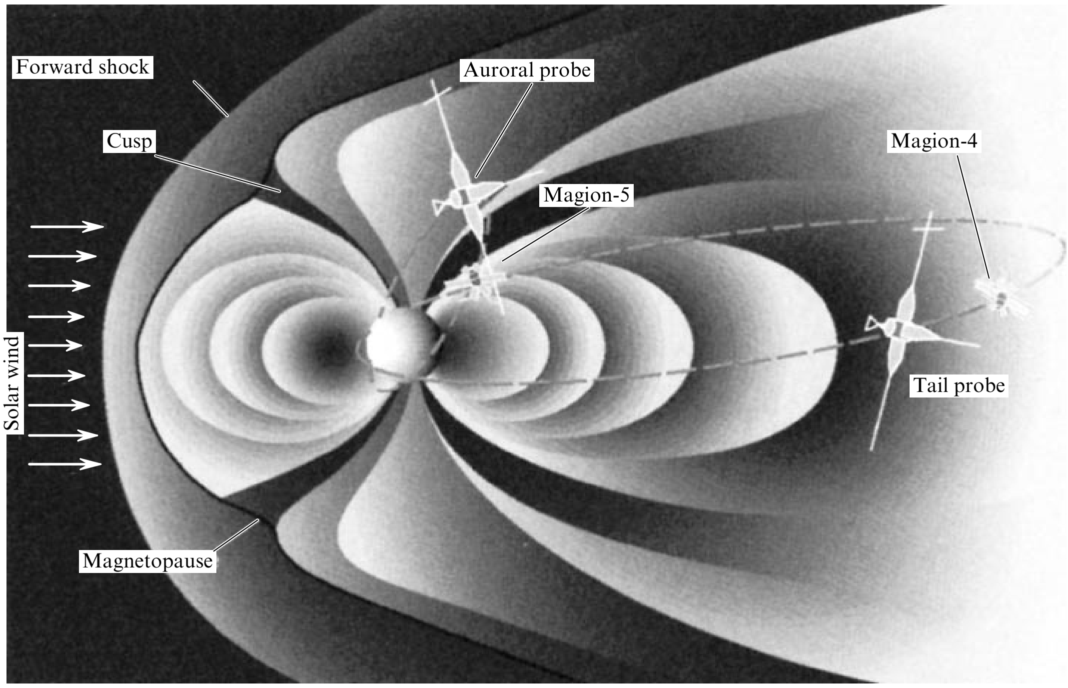

Figure 11. The Interbol project.

which enabled rapid data storage exactly near the front. There was also a ring memory to store the prehistory of the shock crossing.

Due to the complex approach to carrying out the research, the measurement of all necessary and, most of all, key characteristics of the studied processes, the possibility of 'teaching' the onboard devices, and the flexibility in building the program of measurements and their high time resolution at the shock crossing instant, the internal structure of shock front was studied and the physical processes responsible for shock formation, as well as particle acceleration and heating were identified. A deeper insight into the process of ion thermalization in supercritical shock waves due to their front instabilities has been one of the important results of this research.

It is worth remembering that V A Kotel'nikov was personally interested in the results of experiments performed by Intercosmos-23 and actively supported at all stages the realization of this complex program of collisionless shock studies.

Intercosmos-24, launched in September 1989, became one of the first perestroika scientific satellites. Its distinctive feature compared to other satellites of this series has been scientific data acquisition, not only in the Intercosmos collaboration countries, but also in the USA, Brazil, Canada, Finland, Japan, and New Zealand.

The goal of the launch was complex research of very low-frequency (VLF) electromagnetic wave propagation in the Earth's magnetosphere and the waves' interaction with fast charged particles in the radiation belts. An active experiment was also planned to study VLF-wave propagation in the Earth's magnetosphere and magnetospheric plasma processes, hence the name of the project — Aktivnyi (Active).

Intercosmos-24 had to significantly enlarge information available at that time on the plasma shell of the Earth located at altitudes from 100 to 500,000 km and its interaction with the Earth's magnetosphere. Scientists counted on estimating the effects of many processes on the near-Earth plasma: generation of magnetic storms influencing human health, aurora particle drop-out, the effect of many radio transmitters producing a radiohalo around the Earth, lightning discharges, etc.

For more precise and detailed studies of wave processes, the Magion-2 subsatellite constructed in Czechoslovakia had to be operated in tandem with Intercosmos-24. The scientific payload of both satellites was designed in the Soviet Union, Hungary, Bulgaria, Czechoslovakia, the GDR, Poland, and Romania. It was planned that the subsatellite, after detaching from the main satellite, would be flying for several months immediately close to it (at a distance from several meters to 10 km). Unfortunately, a failure in the engine device and the VLF-generator did not allow the full performance of the program.

Shortly after the launch of Intercosmos-24 in 1989, the intention to start active research of the plasma shell around the Earth was declared. For this purpose, the project Aktivnyi-2 was planned to be realized in the first half of the 1990s. In 1990, this project was officially given a new name APEX (Active-Plasma Experiment). The project was aimed at studying the influence of modulated electron and plasma beams on the terrestrial ionosphere and magnetosphere. During the experiment, it was planned to estimate electric fields and currents mediating the ionosphere–magnetosphere interaction, as well as to assess charged particle fluxes along the field lines of the geomagnetic field. The measurements had to be carried out by the Intercosmos-25 satellite, which scientific payload partially included a replica or an upgrade of the Intercosmos-24 devices.

The satellite was launched in December 1991. In 10 days, the microsatellite Magion-3, manufactured by the Czech Republic and Slovakia, separated from the basic spacecraft. Its scientific payload allowed taking measurements of almost the same physical quantities as the main satellites. This time the sub-satellite had no correcting engine, and keeping it at a distance of ten to a hundred meters was provided by the engine device of the primary satellite.

Intercosmos-25 successfully obtained many interesting results. All scientific units operated normally. A series of active experiments on studying emission from plasma and electron beams and their detection was carried out by the subsatellite.

In the 1990s, after the dissolution of the Soviet Union, the organizational structure of the Intercosmos Council was de jure dissolved. The Council for Mutual Economic Assistance, the Warsaw Pact ceased to exist. In most of the countries participating in the Intercosmos program, the economical and political regimes changed, but scientific and personal relations between scientists have persisted.

One of merits of the Intercosmos program was the increasing from year to year internationalization of Soviet cosmonautics. For example, in the Vega (Venus–Galley) project realized in 1984, in addition to the countries permanently collaborating on the Intercosmos program, scientists from Austria, Germany, and France participated in the manufacturing of the scientific payload installed on automatic interplanetary stations Vega-1 and Vega-2.

The first part of the flight program of these stations was aimed at exploring the atmosphere and surface of Venus. To this effect, balloon-borne probes were used for the first time. During the second part of the program, the stations approached the Galley comet and after 450 days of flight, in March 1986, they passed near the comet's core at a distance of about 10,000 km. In the experiments, the size and form of the cometary core were determined along with the surface properties and the temperature and chemical composition of the gas, dust, and other parameters of the comet. In addition, television pictures of the comet were recorded and transmitted to Earth.

Planetary projects Phobos and Mars-96 and astrophysical missions Kvant and Spektr series were prepared under a broader international cooperation.

The Intercosmos program was in fact continued in the middle of the 1990s during the realization of the largest international project, Interbol (Fig. 11), in which 14 countries participated. The project became a part of a broad international program coordinated by the Inter-Agency Consultative Group (IACG), including representatives of the ESA, NASA, the Russian Space Agency, and the Institute of Space and Aeronautical Science (Japan).

The Interbol multisatellite project became one of the most successful missions aimed at the studies of physical processes in near-Earth space during the whole history of solar–terrestrial relations research in the Soviet Union and Russia. During the realization of this project, a system consisting of two pairs of satellites was constructed and realized: the primary satellite, Interbol-1, with subsatellite Magion-4, and the subsidiary satellite Interbol-2 with subsatellite Magion-5. This setup allowed making simultaneous measurements in different parts of the Earth's magnetosphere and enabled the separation of spatial and time variations of the measured parameters.

The Interbol project collected the unique (in significance, volume, and quality) experimental material. It became possible first of all due to much more extensive data transmission capacity from the spacecraft to the ground compared to the previous Prognoz series, and to simultaneous multisatellite observations from both close and remote distances in the Earth's magnetosphere. The lifetime of the satellites was much longer than their assured life. These factors were crucial for providing a high scientific level of the results obtained. The results of the conducted research were published in more than 500 papers diverse in themes and approaches to the analysis of measurement results.

During the realization of this project, new important data had also been obtained on the long-term impact of different space factors on the onboard payload and functionality of technical systems, which yielded valuable recommendations for developers of space technologies.

Presently, several new large international space projects are under preparation. The impetus given by the Intercosmos program and personally by V A Kotel'nikov was crucial for surviving the hard times of the 1990s and, despite the political woes, for preserving and continuing scientific collaboration with colleagues from Eastern and Western Europe at a new and higher level. Now full scientific collaboration in space has been restored with Poland, Bulgaria, and France. A new agreement with the Czech Republic is under preparation.

The experience of Intercosmos turned out to be also very important in establishing relations with CIS countries.

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Development of Kotel'nikov's sampling theorem

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1. Introduction

The name of Academician V A Kotel'nikov means a full epoch in the development of communication systems, radio engineering, and radiophysics. His greatest research achievements had a considerable impact on scientific progress throughout the world. Among them, one should mention his *sampling theorem* [1], the theory of potential noise immunity, which provided scientists and engineers with an instrument for the synthesis of optimal systems for signal processing in communication systems, radar, radio navigation, and other fields, and finally, the development of planetary radars admitting of basic astronomic research with their help.

In 1932, Kotel'nikov prepared a conference report, "On the transmission capacity of 'ether' and wire in electric communications." In this report, he gave the first formulation of the famous sampling theorem, one of the basic theorems in communication theory. This report was published, as a small edition, in 1933.

Let us consider below recent developments of the sampling theorem, its relation to the filtering of continuous signals using discrete observations, and the informational aspects of numerical simulation in the digital processing of complex signals.

2. Kotel'nikov's sampling theorem

Sampling theorem in the time domain. *A continuous signal $x(t)$ whose spectrum is limited by a maximal frequency F_{m} can be unambiguously and losslessly restored from its discrete samplings taken with a rate of $F_{\mathrm{discr}} \geqslant F_{\mathrm{m}}$. The algorithm of*