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Science & Technology

USSR: Space

Soviet Space Program to the Year 2000

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Introduction

[Text] ***In this brochure, the principal space research projects planned by the Soviet Union for the period up to the year 2000 are, for the first time, published in rather great detail. The brochure is intended for a wide range of readers interested in space research problems.***

Space research rightfully occupies a foremost place in the annals of the outstanding scientific and technical achievements in the 20th century. The launches themselves of the first space vehicles were of exceptionally great importance because they marked penetration into a completely new field of research and occasioned the birth of new scientific areas. And if in the not so distant past, man could, for the most part, directly study only the "environs" closest to the Earth—those bounded by the lower atmosphere of the planet—the entire solar system, in theory, became accessible to man when he went into space.

Research in space opened up completely new horizons in scientific investigation, horizons that nobody could have dreamed of. For example, in astrophysics this research brought about a true revolution. In other cases, space experiments supplemented traditional methods for physical measurements substantially. Many scientific disciplines broadened the range of their research considerably. As a result, over a very short period of time (a little more than 30 years), the modern front of science in space was formed.

The entire range of its tasks can be divided arbitrarily into several major fields. One of them is the study of the space nearest Earth. In turn, that field of research can also be broken down into several narrower subdivisions—namely, studies of the upper atmosphere, the radiation belts, the Earth's magnetosphere, the interplanetary medium and variations in their parameters as a function of solar activity. Space research of this kind is usually called research of near-Earth space.

The study of celestial bodies of the solar system by means of unmanned probes is an independent field of research. The primary attention here, until recently, has been devoted to large bodies: the moon and the planets and their satellites.

The field of extra-atmospheric astronomy includes research of "deep" space (the Universe). Such investigations are made by indirect, remote methods that use telescopes and other special scientific instrumentation carried on space platforms.

Near Space

The study of near space became one of the earliest directions taken in space research. In the second half of the 1940s, a series of rocket experiments was carried out during which the first direct measurements of the vertical dependences of atmospheric parameters were made. Over the course of the rocket launches, the equipment for performing the subsequent satellite stages of research was also perfected.

The first and second artificial satellites carried a minimum of scientific instrumentation, but even that was adequate for obtaining substantial volume of scientific results. The Earth's radiation belts—aggregations of charged particles trapped by the Earth's magnetic field—were the first discovery of the space era. Thus, the great efficacy of artificial satellites as a new instrument of scientific research was demonstrated from the very beginning.

The third Soviet satellite performed a great deal of geophysical research. For the first time, direct high-altitude measurements were made of the Earth's magnetic field, of soft corpuscular solar radiation, and of atmospheric composition and density; the electron concentration in the ionosphere and the density of the meteor matter around the Earth were also measured. The results of those experiments were a necessary stage for subsequent programs that were more complete and narrower in focus.

Scientific research in near space was later developed extensively within the framework of the multipurpose Cosmos program. Regular launchings of the Cosmos satellites began in March 1962, and there have been almost 2,000 of them. The satellites of this series are also employed for orbital testing and development of new space equipment, individual mechanisms and systems, and structural elements of space vehicles.

In addition to the Cosmos satellites, special space vehicles that are designed to operated in greatly elongated orbits are developed to study phenomena on the sun and conduct research on solar-terrestrial relationships. Two such satellite systems under the name Elektron were launched in January and July of 1964. Each system consisted of two vehicles put into substantially different orbits by a single booster. The altitude of the apogee of the first orbit was about 7000 km, whereas that of the second was about 70 000 km. The altitude of the perigee of both was 400 km. The combined scientific instrumentation, the large orbital inclination, and simultaneous measurements by satellites with high and low apogees enabled the discovery of a number of new phenomena in various regions of the magnetosphere that no previous space vehicle had ever explored.

Launches of the specialized Prognoz heliogeophysical observatories, which have immense capabilities for carrying out research on solar activity and its effect on physical phenomena that take place on the Earth, in the immediate environs of the planet, and in the interplanetary medium, began in April 1972. The Prognoz vehicles are launched into orbits with an apogee of about 200,000 km and a perigee of 500-900 km. In such an orbit, a satellite is capable of making measurements of three regions of space that differ substantially in terms of their properties: the magnetosphere proper; the interplanetary medium, which is directly adjacent to it and on which the geomagnetic field has virtually no effect; and the boundary region of the interaction between solar plasma and the magnetosphere, a region that experiences the greatest disturbances.

The research made it possible to formulate a qualitative and, in some cases, a quantitative picture of the physical processes taking place in near-Earth space at distances of tens and hundreds of Earth radii, as well as their relationship to processes in the interplanetary medium. It has become clear that the Earth's ionosphere is only the lowermost part of the Earth's extensive plasma envelope. Above it lies the magnetosphere, filled with plasma, which is constantly "replenished" by the solar wind, the flow of plasma escaping from the sun.

The solar wind is highly variable in time, which is related to solar activity. During powerful solar flares, when enormous masses of plasma are ejected from the corona, the density, temperature and velocity of the solar wind greatly exceed their mean values. During the series of solar flares in August 1972, for example, the plasma detectors on the Prognoz and Prognoz-2 satellites detected record levels of plasma density and ion temperature. The velocity of the solar wind reached 2000 km/s.

A shock wave is formed when a supersonic flow of solar wind strikes the Earth's magnetic field. The plasma just ahead of the shock wave front is heated to tens of millions of degrees and flows around the Earth's magnetosphere. The lines of force of the magnetic field at low and middle latitudes, where they are not far from the Earth's surface, compress somewhat. At high latitudes, they are copmpressed quite severely. The lines emanating from the polar cap regions are virtually "blown away" in a direction away from the sun. These lines of force go "back" to the nighttime side for millions of kilometers, forming the "tail," or plume, of the magnetosphere.

Because of the transfer of solar wind energy to the magnetosphere, the energy gradually accumulates in the tail, which sooner or later results in a restructuring of the magnetosphere's configuration and the dissipation of energy. Streams of accelerated electrons are formed which enter the ionosphere and cause an optical glow—the auroras. The flow of powerful currents results in magnetic storms capable of disrupting radio communications in the polar regions. In turn, these magnetic field disturbances induce strong electrical fields and currents in telephone lines, at times even putting them out of operation. Electrical currents induced in long pipelines are a cause of their increased corrosion.

Very interesting results were obtained during the Soviet-Czechoslovakian Intershok experiment performed on the Prognoz-10 satellite. The primary goal of this project was to study the fine structure of the near-Earth shock wave, the boundaries of the magnetosphere, and the disruptions in the parameters of the interplanetary medium associated with the ejection of matter during solar flares. To a considerable extent, this also determined the choice of the Prognoz satellite for performing the experiment. Its orbital apogee was about 200,000 kilometers, and the front of the near-Earth shock wave was situated at a distance of 100,000-150,000 km. Thus, the satellite not only intersected it, but was also, for a quite long time, in the space just ahead of the shock wave front undisturbed by the solar wind. The repeated detection of a strong near-Earth wave and weaker interplanetary shock waves made it possible to investigate their characteristics under different conditions and as a function of the parameters of solar wind plasma flow.

One of the principal features of the experiment was its comprehensive nature, the measurement of all the key characteristics of the processes under study. The onboard computer ensured flexible control of the program and, what is especially important, "taught" the entire array of instruments to recognize the moment of shock wave intersection. That made it possible to quickly record information near the front. A high temporal resolution of measurements was thereby ensured, which for the first time made it possible to study the internal structure of the wave front and to identify the physical processes responsible for the formation of the structure and for the heating and acceleration of particles.

Solar wind plasma penetrates into the magnetosphere through unique gaps, or funnels, that form on the boundaries of the magnetosphere, and it constitutes a considerable part of the plasma "population" of the magnetic tail of the planet and the so-called plasma mantle inside the boundaries of the magnetosphere. Investigations of the paths of penetration and migration of plasma through the magnetosphere were made by means of natural tagged atoms—ions of helium and oxygen (on the Prognoz satellites), and also from the glow of excited molecules in the upper layers of the atmosphere (Soviet-Bulgarian experiments on the Intercosmos-Bolgariya-1300 satellite and Soviet-French experiments on the Aureol satellite).

Investigations of the Earth's magnetosphere have facilitated the formulation and confirmation of a number of highly important physical ideas. Among the most important of them, obviously, is the view that plasma is a medium whose dynamics is determined not only by the ions and electrons that constitute it, but also by the broad spectrum of wave motions characteristics of the plasma.

Study of the Earth's magnetosphere is a complex experimental task. Here researchers encounter difficulties directly opposite those in laboratory plasma: space probes cause virtually no disturbance of the plasma surrounding them, and their measurements can, in an absolute sense, be regarded as point measurements; but the number of points at which measurements are made is limited by the number of space vehicles used. For that reason, understanding the cause-and-effect relationships among phenomena in the complex magnetospheric-ionospheric system requires simultaneous probing of the various of its critical regions with a rather extensive network of satellites and ground stations supporting them.

Modern magnetospheric investigations are characterized by a changeover from the individual measurements for the purpose of determining structural parameters in randomly or intuitively chosen places to the selective study of dynamic phenomena in the magnetosphere based on a by-now-familiar but rough model using a complex of instruments on several simultaneously operating space vehicles.

For example, since the main reservoir of energy of a magnetospheric substorm is the tail of the magnetosphere, the appearance of a storm in the Earth's magnetosphere and atmosphere must be studied with simultaneous monitoring of the state of the tail. Particular attention must be devoted to two regions. The first of them is the plasma layer at an altitude of 10-30 Earth radii. It is precisely there that the processes of conversion of magnetic field energy into the energy of plasma and electrical currents are played out. The second region is situated over the auroral oval—the auroral region—at an altitude of 10,000-20,000 km. Plasma processes develop there which are responsible for the conversion of electrical energy back into the energy of accelerated particles, which cause auroras and other substorm manifestations.

It is into those regions that two satellites of the Prognoz type are expected to be sent in the early 1990s to perform simultaneous measurements of the parameters of plasma, electrical and magnetic fields, and accelerated particles. In addition, since magnetospheric plasma is an extremely variable object (in both time and space), in order to separate the spatial and temporal variation of the detected parameters each of the satellites will operate in combination with a small satellite (a subsatellite) constructed in Czechoslovakia. In order to enhance the temporal resolution of the instruments carried aboard the satellites, it is proposed that they be controlled by an on-board computer. The program loaded into the computer will make it possible to identify key plasma phenomena from the signals received and, in turn, to issue commands for accelerated measurements. This will make it possible to perform a more thorough analysis of the possible mechanisms of the phenomena and to reconstruct a detailed picture of development of a magnetospheric substorm.

The project has been named Interbol. Scientists from the USSR, Czechoslovakia, Bulgaria, Hungary, Poland, GDR, Rumania, Cuba, Austria, Italy, Canada, Finland, France, Sweden and the European Space Agency will participate.

The principal objective of the project is a study of the physical mechanisms responsible for the transfer of solar wind energy into the magnetosphere, its accumulation there, and its subsequent scattering (or dissipation) in auroral regions of the magnetosphere and in the ionosphere and atmosphere during magnetic storms. The system of Interbol satellites will enable investigation of two main aspects of magnetospheric activity: the cause-and-effect relationships and the physical mechanisms of the phenomena.

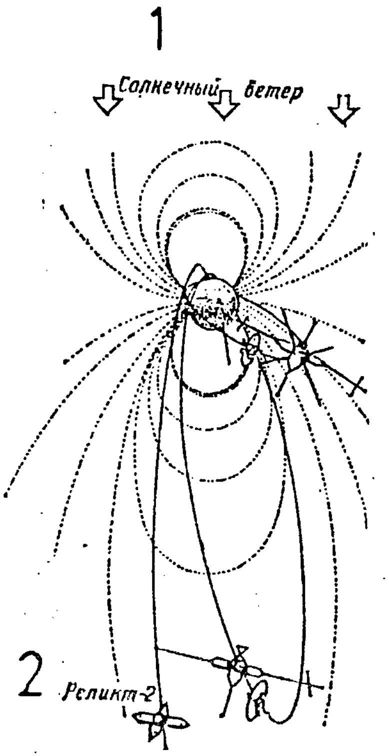

Fig. 1. Trajectories of auroral and tail probes in Interbol project. Data on the orbits of these vehicles are given in the text. The orbit of the space vehicle Relikt-2, which will be used in making plasma and magnetic measurements synchronous with the Interbol project, is also represented schematically.—Key: 1. Solar Wind—2. Relikt-2

Simultaneously with local satellite measurements, a scanning photometer carried aboard the "auroral" vehicle will be used to observe the global picture of the auroras. Provision is also being made for the deployment of an extensive network of ground stations in the northern hemisphere for magnetic measurements and optical observations of auroras.

Since the scales of study of physical phenomena differ by several orders of magnitude, the separation of the spatial and temporal variations of plasma requires the capability for monitoring the variation in distance between satellite and subsatellite. For the auroral system it must vary from hundreds of meters to hundreds of kilometers; for the tail system, from tens to several tens of thousands of kilometers.

Provision is being made for investigation of the plasma and magnetic structure of remote regions of the magnetospheric tail (at more than a million kilometers from the

Earth) that will be performed simultaneously with the measurements made from aboard satellites of the Interbol system. They will be made by an instrument package carried on the astrophysical satellite Relikt-2, which must be launched into orbit around libration point L_2.

The importance of the study of the processes in the Earth's magnetosphere stems, to be sure, not only from the fundamental and general physical importance of this research. The interrelationship between, on the one hand, processes on the sun and in near-Earth cosmic plasma and, on the other, everyday life on the Earth becomes increasingly evident with each passing year. The amount of energy associated with the corpuscular solar radiation that enters the Earth's magnetosphere is 10^{12} W, which may not be very much in terms of the scales of space. Nevertheless, many of its effects—magnetic storms, disruptions of radio communications, electrical power line failures, etc.—are well known.

Most scientists do not question the fact that solar activity affects the Earth's climate. Of course, radical climatic changes do not occur before our eyes. It is a long process, a result of the operation of a great many factors. We are witnesses of seemingly instantaneous fluctuations of climate. It is interesting, for example, that the effect of a slowing of the Earth's rate of rotation was detected as a result of the solar "storm" in August 1972, and that, in the opinion of some scientists, led to local weather anomalies on the planet.

Hypotheses and conjectures on the causes and effects of solar-terrestrial relationships have, especially in recent years, been many. However, putting the hypotheses on firm scientific ground will require the acquisition of a good deal more experimental data on processes on the Earth, in near space, and in the upper atmosphere and the accumulation of adequate factual material on the interaction of those processes among themselves and with solar activity. That is one of the most important tasks of space physics today.

Scientists are hoping to obtain extensive scientific results on the physics of the plasma phenomena being played out in near-Earth space in the course of the implementation of a project for experimental research that uses a system of small space laboratories (SSL) outfitted with solar sails. The main objective of the project, which has been given the preliminary name Regatta, is the organization of multiprobe measurements with high spatial and temporal resolution. The deployment of a rather dense satellite system, in addition to solving fundamental problems in plasma physics, would at the same time be an important element in investigations of the influence of solar activity on the Earth's atmosphere, climate and biosphere.

A small space laboratory has been developed by scientists and specialists of the Space Research Institute, USSR Academy of Sciences. Its design meets the high requirements for magnetic and chemical purity and orientation accuracy and is distinguished by relative simplicity and low cost and a capability for carrying a rather large payload. The laboratory is designed for a long active lifetime.

It is being proposed that the Regatta project interact with the European Space Agency's Cluster program, whose objective is to investigate the fine structure of processes in near-Earth space.

In problems of magnetospheric physics, an ever-increasing amount of attention will be devoted to active, or controlled, experiments. Until recently, only passive research methods were used in observational space physics. Those methods consist of the measurement of the parameters of natural phenomena and their corresponding physical explanation. Today, more and more attention is being devoted to active experiments. They make it possible to bring the methods for study of processes in the magnetosphere closer to the methods used in plasma physics laboratories. All near-Earth space is becoming an enormous natural plasma laboratory in which phenomena of interest to researchers are being artificially stimulated.

There are various means and methods for affecting the space medium: beams of accelerated particles, artificial plasma, electromagnetic emissions, etc. Controlled experiments can be classified into two main groups in accordance with the nature of the effect. The first consists of experiments of the "test particles" type (similar to the tagged atoms method), which do not change the qualitative state of the medium. Experiments involving the injection of low-power electron and ion beams can be included here, as well as experiments involving the release of barium and lithium vapors. In recent decades, they have become almost routine experiments. Several such projects have been carried out in the USSR and in other countries. The second group of active investigations includes experiments with powerful electron and ion beams that can change the state of cosmic plasma appreciably.

Very-low-frequency (VLF) radio waves can also be an active diagnostics tool. The magnetosphere is a virtually ideal waveguide for such waves, thereby ensuring their repeated propagation between magnetically coupled points.

In the first stage, powerful surface radio transmitters were used for the excitation of a VLF wave in the magnetosphere. However, a considerable part of their energy is lost due to scattering in the atmosphere and lower ionosphere. That can be avoided if the transmitter is placed aboard a satellite. Calculations show that a space transmitter of several kilowatts can produce an electromagnetic VLF wave in the magnetosphere that is more powerful than that produced by a surface transmitter of 1 MW. Consequently, it is also possible to more effectively initiate a broad range of phenomena which will be a response of the magnetosphere to a wave propagating in it. Such phenomena include, in particular, the "leakage" of electrons and protons from the

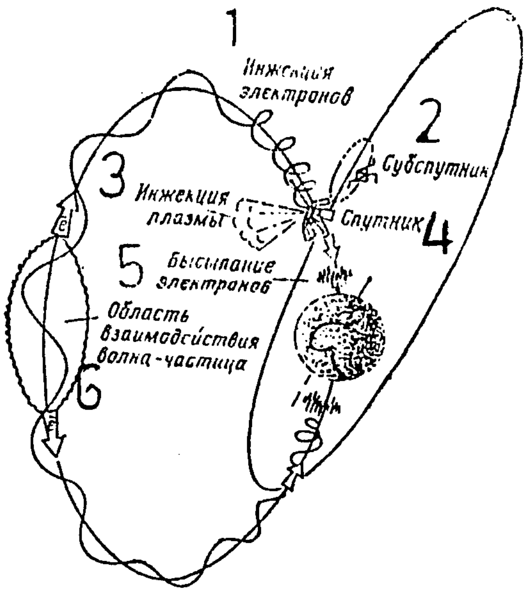

Fig. 2. General diagram of APEKS experiments.—Key: 1. Injection of Electrons—2. Subsatellite—3. Injection of Plasma—4. Satellite—5. Electron Leakage—6. Wave-Particle Interaction Region

radiation belts and the excitation of powerful plasma oscillations and their heating of ionospheric plasma.

The APEKS project, which is planned for 1989, will be devoted to a controlled study of the electrodynamic link between the auroral ionosphere and the magnetosphere. Its basis will be satellite plasma experiments with the injection of beams of electrons and plasmoids into the magnetosphere. The head organization for the preparation and realization of the project is the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences. Work on the project is being carried out in international cooperation with the scientists of Hungary, GDR, Bulgaria, Poland, Rumania and Czechoslovakia.

Such experiments, carried out during recent years in the United States and Japan (with the participation of other countries), have made it possible to understand much in the processes of interaction between fluxes of charged particles and ionospheric plasma at altitudes of up to 300 km. In the APEKS project, active experiments will be carried out at altitudes of up to 3500 km. APEKS will become a logical extension of the active rocket experiments ARAKS (USSR-France) and PORKUPAYN (USSR-Sweden).

Two French research rockets, launched from Kerguelen Island, were used in the ARAKS project. Each rocket carried a 15 kW Soviet plasma gun which injected beams of electrons with energies 27 and 15 keV into the ionosphere and magnetosphere. In the magnetically coupled region (Arkhangelsk Oblast) and to the south of it, there were optical and radar stations that made it possible to detect and register the entry of the electron beam into the northern hemisphere. In the course of the experiment, the excitation of waves caused by the beam of electrons in the Earth's ionosphere and magnetosphere was identified and monitored and the conditions for their propagation were studied.

The principal scientific objectives of the APEKS project are the modeling and initiation of auroras and radio emissions in the auroral region; the investigation of the dynamics of molecular beams and plasmoids in near-Earth plasma; the study of the nature of the electrodynamic link between electromagnetic waves in the magnetosphere and ionosphere; determination of the radio emission properties of modulated beams of charged particles and plasmoids; and the search for nonlinear wave structures of the type of electromagnetic solitons under disturbed conditions.

In addition to plasma investigations from aboard a satellite, the project also includes surface, balloon and rocket observations. During individual time periods, measurements will be made along the entire vertical profile (from the point at which the satellite is situated to the Earth's surface). Although the main direction in the APEKS project is the implementation of active experiments, observations of geophysical phenomena in the absence of injection of beams and plasma (in a so-called passive measurement mode) will also be important.

The procedural basis of the active experiment will be the artificial injection of a beam of electrons and/or plasma from aboard a satellite, with the simultaneous registration of phenomena generated by the beam injection, its interaction with the background medium, and the beam's propagation in the medium. A fundamentally important feature of the project is the synchronous measurement of the principal physical parameters of the medium, the beam, and the generated fields by instruments carried on two spatially separated space vehicles (the main satellite and the subsatellite). In the process, simultaneous measurements will be made both at different relative distances (from 0.01 to 1000-2000 km) and in different regions (different in terms of areas of disturbance of the medium and beam propagation) of the magnetosphere and ionosphere.

In the future, similar active experiments will be extended to altitudes as great as several Earth radii. That will make it possible to directly model and analyze the magnetospheric processes that determine the occurrence of various auroral phenomena. For that purpose, the combined international Apogey project has been proposed for 1995, to be carried out on the basis of the APEKS-2 project and the West German Impakt project. The scientific program of the project, the composition of the instrumentation, and the cooperative framework are now in the discussion stage.

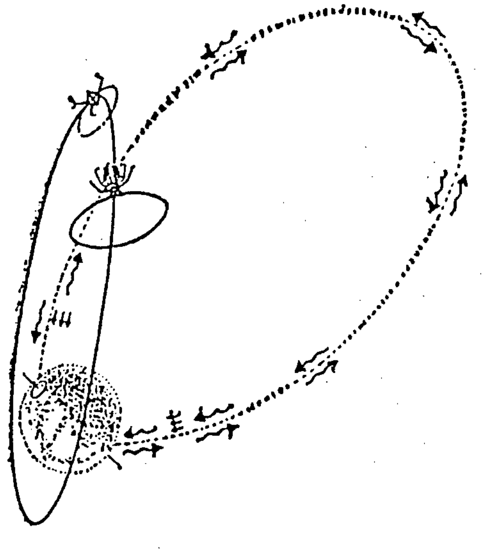

Fig. 3. Diagram of experiments of the Aktivnyy project.

In the future Aktivnyy project, the means for affecting the surrounding medium will be the VLF electromagnetic energy emitted by an on-board satellite transmitter with an antenna that is unfolded in space.

The purpose of the project will be a comprehensive investigation of the propagation of electromagnetic waves in the VLF range in the Earth's magnetosphere and also their interaction with energetic particles in the radiation belts.

The Aktivnyy project is the first space experiment in which a controllable subsatellite will be used in investigating the spatial structure of physical phenomena accompanying the injection of powerful VLF radiation into the magnetosphere. The subsatellite will become a unique probe slowly separating from the main vehicle. Later, the distance between the satellite and subsatellite will be varied within a range of a hundred meters to a hundred kilometers with a vernier propulsion system. Thus, it will be possible to investigate not only the nearby region of radiation, but also phenomena in the intermediate and distant regions.

Scientists from the USSR, Bulgaria, Hungary, GDR, Poland, Rumania and Czechoslovakia are participating in the Aktivnyy project.

The Aktivnyy-2 project, slated for the first half of the 1990s, will be a further dvelopment of the "Aktivnyy" and APEKS experiments. The objective of the project is a study of the effects caused by the excitation of VLF emissions in the Earth's ionosphere and magnetosphere and the injection of plasma and electron beams and neutral gas. A study is being made of the possibility of increasing (in comparison with the preceding experiments) the power imparted to the active effect and the use of plasma and beam antennas. As in preceding experiments, it is proposed that a subsatellite be used in order to obtain data on physical processes at different distances from the equipment used to affect the medium.

Space research in the field of solar-terrestrial physics also calls for the study of the sun itself. For example, the comprehensive program for the KORONAS satellite project provides for determination of the characteristics and location (corona or chromosphere) of the solar accelerator and determination of the parameters of solar plasma by classical spectroscopic methods and new methods using, for example, detection of radiation pulsations from flare arches or nuclear γ-lines). The main objective of the experiment is the search for precursors of flares in different spectral ranges and clarification of energy release mechanisms.

Observation of different manifestations of solar activity and investigation of its influence on near-Earth space is a traditional problem for a solar space observatory. A special feature of the KORONAS project is that the satellite will carry instrumentation both for observation of phenomena on the sun and for the analysis of near-Earth plasma.

The project's tasks also include investigation of the solar corona and the region of accelerated solar wind with an extraterrestrial coronagraph and a radiospectrometer.

KORONAS should also include one of the first experiments in the field of helioseismology: observation of the fundamental harmonics of solar oscillations. The solar spectrum of characteristic oscillations of the sun contains information on how temperature changes from the sun's surface to its core, and also on the dynamics of the inner layers of the sun. Thus, together with neutrino astronomy, helioseismology makes possible a direct study of the interior of the star closest to us.

The experiment is expected to be carried out on the AUOS-SM-IK space vehicle, which is a modification of an updated unmanned all-purpose station with a sun sensor system.

The head organizations for the KORONAS project are the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences, and the Physics Institute, USSR Academy of Sciences. Institutes in Poland and Czechoslovakia will collaborate in the project.

If the KORONAS project is slated performed right in the maximum phase of solar activity, another "solar" project—Neytron—will be carried out during the period of a relatively quiet sun. That will make it possible to obtain information on stationary processes in active plasma formations in the absence of the secondary effects associated with flare phenomena and on strongly nonstationary processes during powerful flares that usually arise in the descending phase of the solar activity minimum. A scientific objective of the project is to study during this period the processes of the conversion of energy in the solar atmosphere (from the photosphere to the corona) to thermal heating and nonthermal components. Fluxes of fast neutrons and short-wave solar radiation in the range of ultrasoft X-radiation to gamma radiation will be investigated for this purpose.

The Neytron project differs from similar previous projects (both Soviet and foreign) with improved instrumentation parameters—lens speed (for the gamma neutron spectrometer), spatial resolution (for the X-ray telescope) and energy resolution (for the X-ray spectrometer).

The experiment for determining the spectra of neutrons from flares is, in general, the only one of its kind in the world. The neutron component of flare processes on the sun is virtually unstudied—until now, only three events have been registered, and the instrumentation was not being used to study neutrons and did not provide any information on their spectrum.

The project is expected to be carried out through the joint efforts of institutes in the USSR, GDR, Poland and Czechoslovakia.

Solar System

The moon was the first celestial body of the solar system to be an object of space research. Our natural satellite was studied from flyby and orbital vehicles and landers. The chemical composition of its rocks was investigated. Photographs of its surface were taken from a close distance. The world's first soft landing on the lunar surface, by the Soviet Luna-9 unmanned station, immediately deflated the "lunar dust" hypothesis, whose history goes back almost to the time of Galileo. A study of the panoramic photographs transmitted by the station to the Earth indicated that the formation of the lunar surface was, indisputably, not a single-event process. Important information on the physical and mechanical properties of lunar soil was also transmitted by the Luna-13, which also made a soft landing on the lunar surface.

New stations of the Zond series, whose mission included testing of the on-board equipment for prolonged space flights, photographed the moon from a close distance and delivered the exposed film to the Earth.

The flights of the unmanned stations Luna-16 and Luna-20, which delivered samples of lunar rock to the Earth, represented a natural step in the work of Soviet scientists studying the moon. The development of lunar rovers made it possible to carry out scientific experiments not only at the landing site of the unmanned vehicle, but also at various distances from it.

The gap in study of the moon by space vehicles which has occurred in recent years has been necessary in order to think through the results and to plan and prepare new programs. The Earth's only natural satellite remains, as before, an extremely interesting object of research.

In the early 1990s, plans call for carrying out a global photographic survey of the lunar surface from aboard an artificial lunar satellite. This will make it possible to compile detailed video atlases, morphological and geological maps, maps of the chemical composition and radioactivity of the surface, and maps of magnetic, gravitational, and thermal fields. Landing sites for the space vehicles of future expeditions to the lunar surface and sites for future research will be based on them.

Plans call for the delivery of soil from the far side of the moon in 1996.

The moon will apparently also become the first extraterrestrial base for earthlings on man's path to a deeper penetration into space. As noted by Academician S. P. Korolev, the organization of a permanent scientific station on the moon (and later an industrial complex as well) will make it possible to use the untouched and still unknown resources of our satellite for science and the economy.

The first interplanetary path was blazed on 12 February 1961, when a multistage booster rocket put the Venera-1 unmanned station on a flight trajectory to the planet Venus. In 1967, for the first time in history, radio signals were transmitted to the Earth from another planet: the famed Venera-4 had entered the planetary atmosphere. Direct measurements were made of chemical composition, pressure, density, and temperature, as well as of the electron concentration in the ionosphere. The hydrogen corona of Venus was discovered.

A total of 16 space vehicles of the Venera series and 2 Vega vehicles with landing modules and balloon stations have been sent to Venus. If the first Venera vehicles (up to and including No 8) entered the planetary atmosphere completely, the second-generation stations were consisted of descent modules and orbital units. The descent module entered the atmosphere and the orbital compartment either became a planetary satellite (Venera-9, -10, and -14) or flew above the planet at some distance and then entered an orbit around the sun (Venera-11, -12, -13). The orbital vehicles carried scientific instruments for remote study of the planet on the basis of its emissions in different wavelength ranges, as well as instrumentation for investigation of interplanetary plasma and magnetic fields and for astronomical observations. The Venera-15 and Venera-16 stations were put into the orbit of an artificial Venusian satellite. They carried a large radar antennas, which was used in making a survey of the planet's northern hemisphere.

The first unmanned station of the Mars series was launched in November 1962. A total of 61 radio sessions were transmitted from the station, after which communication with it was lost.

Two new stations, Mars-2 and Mars-3, were launched to Mars in 1971. A capsule reaching the planetary surface was jettisoned from the Mars-2 station, whereas a descent module, which made a soft landing, was separated from the Mars-3. We didn't manage to receive any scientific information from these landing modules. The stations themselves became artificial Martian satellites, and they were used in carrying out 11 scientific experiments, seven of which involved study of the planet—remote measurements of the soil temperature and investigations of surface relief and of composition and structure of the atmosphere.

Four other stations—Mars-4, -5, -6, -7—were launched to Mars in 1973. The objective of the new space experiment was the comprehensive investigation of the planet simultaneously from the orbit of its artificial satellite and directly on the planet. Thus, for the first time in the history of the space program, direct measurements of temperature and pressure of the Martian atmosphere were carried out, on the descent module of the Mars-6 satellite; whereas experiments related to study of its chemical composition (including measurement of atmospheric water vapor content) were made by the Mars-5 artificial satellite.

A good deal of important information was supplied, first and foremost, by the images of Venus and Mars (photographic, television, radar) obtained from a close distance with a high resolution. They made it possible to see what the surfaces of these celestial bodies are like. The images revealed many features of their geological history which were not erased by subsequent stratification and processes (as occurred on the Earth under the influence of the hydrosphere and biosphere). The analysis of the surface structures on the Moon, Venus and Mars and the laboratory analysis of the substance of lunar rocks made it possible to peek into the Early Precambrian history of our planet.

On all planets of the Earth group (which, in addition to Venus and Mars, includes Mercury), distinct traces have been discovered of early and later volcanism, which, along with active tectonic processes, meteor bombardment and various erosional factors, formed the principal surface features. For example, enormous shield volcanoes with elevations of 10 to 25 km have been identified, as well as deep valleys and large-scale benching in the form of scarps.

The space vehicles that landed on Venus and Mars were used in carrying out the first investigations of the nature of the rock that makes up their surfaces. Evidence was found of a differentiation of the matter of the interior of the planet that resulted in the formation of the crust, mantle and core. All this provides prerequisite information for dating the most important processes in the thermal evolution of celestial bodies and for solving such fundamental problems as the chemical composition of the deep layers of the planets and the general laws of mineral concentration in them, the nature of the magnetic field and the laws that governed the formation of the atmosphere and hydrosphere.

Study of the gas envelopes of the planets was of fundamental significance for clarifying the paths of general planetary and climatic evolution. It has been reliably established that on Venus and Mars they are primarily carbon dioxide in chemical composition. Pressure at the Venusian surface is approximately 100 times greater than on the Earth, but on Mars it is lower by a factor of 100-200. The Venusian atmosphere is very hot (surface temperature of about 470°C), whereas on Mars the temperature drops to levels at which the carbon dioxide (from the atmosphere) is condensed at the surface, which gives rise to appreciable seasonal pressure changes. In turn, compounds containing sulfur and chlorine are condensed in the Venusian atmosphere at altitudes of 50-66 km. Such compounds are the volcanic "acidic" hazes of Venus (under the conditions prevailing in the Earth's atmosphere they are washed out by rains and are dissolved in the oceans), as a result of which an extended cloud layer consisting of sulfuric acid and chlorides was formed.

A clarification of these and other features greatly facilitated a better understanding of meteorological processes and also the general problems of interaction between the atmosphere and lithosphere and the release of volatile elements on the planets, which in their climatic characteristics can be regarded as two limiting models of development of our planet. Such a comparison is important, in particular, for studying the influence exerted on the Earth's atmosphere by man's economic activity and also possible climatic changes associated with its pollution.

An investigation of the characteristics of circulation in planetary atmospheres and identification of similar features and differences as a function primarily of the quantity of incoming solar energy, mass and optical density of the atmosphere, and period of planetary rotation will also serve for a better understanding of global meteorological processes on the Earth. From this point of view the results a study of the four-day circulation on Venus (stable zonal flow of gases, whose velocity at the cloud level is 60 times the velocity of axial rotation of the planet itself) and of the mechanism of development of dust storms on Mars are of unquestionable interest.

Significant anomalies of the ratios of the primary isotopes of argon to the isotope forming as a result of the radioactive decay of potassium, as well as the isotopic ratios of a number of other elements—detected by mass spectrometer measurements in the Venusian and Martian atmospheres—indicate definite differences in the formation of their gas envelopes by comparison with the Earth. In addition, these data do not contradict the hypotheses expressed earlier that the quantity of water lost by Venus because of its closeness to the sun may be comparable to the amount of water in the Earth's oceans. But Mars probably experienced more favorable climatic periods in its history, when its atmosphere was tens of times denser and rivers, whose numerous dessicated channels are visible on the photographs taken from aboard space vehicles, flowed on the surface.

The study of the thermal evolution of the planets and paleoclimate is quite intimately related to the general problems of cosmogony. A highly important role here is played by data on the physical properties and chemical composition of the entire array of solar system bodies:

the major and minor planets (and asteroids), comets and also meteoritic dust. The minor bodies, precisely because of their low mass and remoteness from the sun, cannot have changed greatly during the time of their existence and have long preserved the "primordial" matter of the initial gas-dust nebula from which the solar system was formed. They have thus preserved important information on the initial stages of the solar system's formation.

Investigations of minor bodies have already made an enormous contribution to planetary cosmogony. Take, for example, the results of the study of meteorites—unique specimens of space matter which nature itself "sends" to the Earth. Meteorites are fragments of larger bodies (primarily asteroids) and are formed as a result of their destruction during collisions with one another. There is also a class of very small meteorites (so-called Braupley particles), probably of cometary origin. For the time being, however, it is unclear what relationships exist between different types of minor bodies, and a number of their most important characteristics are not known. Comets are especially mysterious. They are of the greatest interest to researchers because they have gas and dust components and thus make it possible to obtain unique information (right down to elemental and even isotopic composition) without a landing on the main body. Such a landing would involve considerable technical difficulties, although projects of such a type are being developed.

Cometary investigations are also extremely important for the diagnosis of physical conditions in interplanetary space. Their use as natural probes represents at the present time the only possibility for investigating sectors of space which, for the time being, are inaccesible to interplanetary stations.

The implementation of the Venera-Halley's Comet project became the first important step in the realization of the program for investigations of minor bodies of the solar system by space vehicles. Two identical space vehicles (Vega-1 and Vega-2) participated in the project. Second-generation Venera unmanned interplanetary stations were used as a base design.

The flight program for the Vega space vehicles was as follows: successive launches on 15 and 21 December 1984. In June 1985 the stations reached the vicinity of Venus. Descent modules, which entered the Venusian atmosphere, were separated from them two days prior to the approach to the planet.

By the impulses imparted by the vernier engines the stations themselves were put into a trajectory ensuring a flyby of the planet and the relaying of information received from the descent modules. Then, as a result of a gravitational maneuver in the Venusian gravity field, the flyby vehicles entered a trajectory for a rendezvous with Halley's Comet, which took place for the first station on 6 March 1986, and for the second, on 9 March 1986.

What were the scientific objectives of the expedition to Halley's Comet? First of all, researchers sought to clarify the nature of its nucleus and its atmosphere. Two approaches were used: first, remote measurements using optical instruments, and second, direct measurements of matter (gas and dust) escaping the nucleus and intersecting the trajectory along which the space vehicle moved. In addition, a study was made of the complex picture of processes which is formed upon the encounter between the ionized component of cometary gas and the solar wind flow.

The Vega project involved the broad participation of foreign scientists at the level of space agencies and institutes and individual researchers. An International Scientific and Technical Council under the chairmanship of Academician R. Z. Sagdeyev was organized for the collective solution of the problems involved in joint work under the project. The entire scientific instrument package of the stations was developed in international cooperation (USSR, Austria, Bulgaria, Hungary, GDR, Poland, United States, France, West Germany, Czechoslovakia).

The results of research on the nucleus of Halley's comet can be summarized as follows. It is a monolithic, elongated body of irregular shape (measurements: 14 km along the greater axis, about 7 km in diameter). Each 24 hours, it loses several million tons of water vapor. Computations show that such "productivity" requires that evaporation take place over the entire surface. The surface of an ice body could have this property. But at the same time the instruments established that the surface is black (reflectivity less than 5%) and hot (approximately 100°C). That, as it were, improbable, contradictory picture fits into a simple model which can be compared with a "March snowdrift": a conglomerate ice and high-melting particles separated from outer space by a layer of black, porous matter with a low thermal conductivity. This layer receives solar radiation, part of which reradiates in the infrared range and part of which is transmitted downward to the ice conglomerate. The water vapor molecules forming as a result of evaporation of the latter diffuse upward through the pores and escape the comet. They carry off individual, finer dust particles. The surface layer in some places on the surface from time to time breaks open (if the layer becomes too thick and the pores are stopped up). Then an "active region" with an especially powerful escape of matter is formed. The porous layer is not very thick: from several millimeters to several centimeters (the estimate requires further refinements). This layer is renewed very rapidly: over a period of about 24 hours. Its upper particles detach and are carried off by gas, and new particles are attached from below.

The low value of the reflection coefficient and its neutral character (it is dependent on wavelength) can serve as an indication that the surface layer in its composition is akin to carbonaceous chondrites—one of the classes of meteorites that combines meteorites that are the most ancient and have been subjected to fewer changes than have others.

Important data on composition of the nucleus were obtained by means of direct measurements of the chemical composition of dust, gas and plasma in the coma along the flight trajectory. These measurements indicated that the flow of gas escaping from the comet consists mainly of water vapor; but there are also many other components—atomic (hydrogen, oxygen, carbon) and molecular (carbon monoxide and dioxide, hydroxyl, cyanogen, etc.). Study bands of approximately ten molecular components (these and others) were also detected in the inner coma. The question of what molecules are the "parent" molecules—that is, those that make up the nucleus itself—is of special interest. Chief among them, apparently, are water and carbon dioxide, but there is much to indicate the presence in the nucleus of other molecules, including organic molecules. The substance of the nucleus, most likely, is so-called clathrate, that is, ordinary water ice in whose crystal lattice other molecules are impregnated. Particles of meteoritic composition, stony and metallic, are mixed with the clathrate. The content of a considerable quantity of complex organic molecules in the matter of the nucleus is a new fact in cometary physics.

We managed to measure the chemical composition of the solid particles which were part of the nucleus but escaped it under the pressure of the gas flows. The spectra of approximately 2,000 such particles were obtained. It turned out that solid particles of cometary dust can be divided into 3 main types: in the first there is a predominance of light elements; in the second, carbon; and in the third, metals. The presence of different kinds of dust particles indicates a complex thermal history of the primary matter of the solar system.

The international space project for the investigation of Halley's comet is important from three standpoints: for the first time ever, an interplanetary station was able to make a close approach to the comet and make all possible measurements of its physicochemical characteristics; it was an unquestionably (by the unanimous opinion of the world scientific community) great success of the Soviet Union (Soviet equipment operated faultlessly); it was also an achievement of international cooperation, again demonstrating the effectiveness and benefit of joint efforts in space research.

Even now scientists are thinking about how not just to "skip by" the nucleus of a comet at an enormous velocity and make the necessary measurements during this very short time, but how to execute a maneuver making it possible for a space vehicle to enter into the tail of any comet and slowly approach its nucleus. Then it could fly at a small distance from the nucleus for a long time and make detailed investigations of it.

It is also possible to select a trajectory for a space vehicle such that in several revolutions around the sun it would meet with ten or so asteroids, which would make it possible to obtain new data on these celestial bodies. An expedition of unmanned vehicles to the asteroid belt can be done with the existing equipment base. Preliminary studies associated with the project (it has been named Vesta) are being worked out through the joint efforts of the USSR, France and the European Space Agency. The division of labor looks as follows. France and the European Space Agency are developing the space vehicle itself for flight around the asteroids. The Soviet Union is participating in the development of the on-board scientific instrumentation, will supply the booster for the launch and is making the landing modules which must "land" on the asteroids and carry out detailed investigations on their surfaces.

However, the first minor body of the solar system whose surface should be reached by a space vehicle is Phobos. A multipurpose international project for investigating the solar system has been given the name of this Martian satellite. Its objective is an investigation of the Martian satellite by remote methods during a flyby at a close distance from it and by direct measurements using small landing probes; investigation of Mars from the orbit of an artificial satellite; investigation of the sun; and plasma research. This project, like the Vega project, is international. Institutions, scientists and specialists from Austria, Bulgaria, Hungary, GDR, Ireland, Poland, Soviet Union, United States, Finland, France, West Germany, Czechoslovakia, Switzerland, Sweden and the European Space Agency are participating in it. Soviet scientists were the initiators of the project.

Approximately 200 days are required for reaching the vicinity of the planet and for entry of the space vehicle into an elliptical orbit around it. Then several more weeks (or even months) are required in order to approach Phobos after executing complex maneuvers for switching from one orbit to another. Since the gravitational pull of the Martian satellite is weak, Phobos can be studied with the "terrestrial emissary" moving slowly at a low altitude above the surface (about 50 m). Periodically the space vehicle must "hover" over the most interesting places to study them in more detail. The flight will last only 20 minutes, but will be the culminating event for which the expedition was, in fact, prepared.

In the closest approach to Phobos, plans call for active remote sensing of it. The beam of a laser carried aboard the space vehicle will "illuminate" a tiny sector of the surface of the Martian satellite only 1 mm in diameter. The power density in the "illuminated" spot will be about 10 million watts. The dust covering the surface in a thin layer and corresponding in its composition to the bedrocks will be vaporized in something of an explosion. The ions forming in the process will scatter in different directions, and some of them will be captured by a special on-board instrument. On the basis of the time it takes for each individual particle to fly from the surface to the vehicle, researchers will be able to determine the nature of the particles and, accordingly, the composition of the matter of which Phobos consists. In another active experiment the probing elements will be streams of ions emitted by an ion "gun."

During the flight over the surface of the Martian satellite, those methods are expected to be used to analyze the soil at approximately one-hundred points.

For the time being, such active experiments in space research practice belong to the exotic category. In the Phobos program extensive use will also be made of traditional methods which have served well in experiments carried out earlier. First and foremost is a television survey of the surface. Scientists are hoping to obtain color images on which details measuring several centimeters will be distinguishable. We recall that the American Viking photographed Phobos from a distance of 300 km and the resolution of the photographs was tens of meters.

Among the other, so to speak, ordinary research methods are IR radiometry, infrared spectroscopy and gamma spectroscopy. The first will make it possible to judge the thermophysical properties of the surface, and the second and third, its mineralogical composition.

Use of a special radar complex that uses pulsed radio sounding is also planned for investigations of the relief of Phobos, its internal structure and the electrophysical characteristics of the soil.

At the end of the low-level flight segment, two landers will separate from the spacecraft and "land" on the surface of Phobos—a long-lived autonomous lander (LAL) and mobile laboratory.

On Phobos, gravity is a thousand times less than on the Earth. That makes it possible to use a small repulsive-force apparatus to move about. It will enable the probe to make jumps spanning tens of meters and to study surface characteristics each time in a new place. The measurement program makes provision for 10 jumps.

The weak gravitational field of the Martian satellite can, on the other hand, hinder the long-lived autonomous lander from performing its research. In order for the LAL to maintain a proper working position—with the landing plate downward—the lander will be anchored to the surface by means of a special harpoon-penetrator. In soft, loose soil, the harpoon can penetrate to a depth of 10 m; in sandstone-type soil, it can penetrate half a meter. The penetrator will be connected to the station by a flexible, metal line which will reel the LAL in and keep it pressed to the surface of Phobos.

One of the tasks of the long-lived autonomous lander is to determine the elemental composition and physical characteristics of the soil at the landing site and to register seismic noise in the body of Phobos. A phototelevision apparatus is expected to be used in investigating the microstructure of the ground and surface details.

The operations program for the lander also includes investigations in the field of celestial mechanics. The principal "tool" for realization of this part of the program will be a radio transmitter. Its signals will be fixed upon simultaneously by all the largest ground radio telescopes located in the Soviet Union, Western Europe, North and South America, South Africa and Australia. This will ensure measurement of the distance from the Earth to the Martian satellite at each moment in time within just 5 m. As a result it will be possible to make a precise determination of the position of Phobos both in a coordinate system referenced to our planet and relative to quasars, the most remote radio sources in the Universe. The collected data will make it possible to refine the principal parameters of the solar system, in particular, the astronomical unit (the mean distance between the Earth and the Sun is usually regarded as an astronomical unit).

The program allocates time for investigations of the surface of Mars itself, its atmosphere, and its plasma envelope, the magnetosphere. Plans call for obtaining television images of Mars and data on the chemical and mineralogical composition of the rocks of whihc it is made, as well as compiling a thermal map of the surface.

Provision is made for collecting data on the vertical distribution of ozone, molecular oxygen, water vapor and dust and for studying temperature and pressure profiles. The measurement techniques will be based on a spectral analysis of the solar radiation passing through the Martian atmosphere. Investigations of the Martian ionosphere are planned.

The Phobos mission can be regarded as the first important step in the realization of a long-range Martian research program formulated by Soviet scientists. The next step is planned for the mid-1990s, when Mars will become the destination of several other space vehicles.

It is planned that the program be carried out in stages. The first stage is slated to be completed in 1994 by two interplanetary vehicles. Each of them will include an orbiter (artificial Martian satellite) for long-term investigations of the planet; a descent module carrying a balloon station and a Martian rover, a cassette with 10 small meteorological beacons and means for planting them in the soil; and penetrating probes jettisoned to the surface for investigating the physicochemical properties of the soil. During the flight of the orbiter, a small satellite will separate from it for the purpose of collecting data for constructing (with a high spatial resolution) a model of the Martian gravitational field. Precise trajectory measurements of the "orbiter-subsatellite" system will be used to perform the research.

The orbiter is slated to perform a wide range of remote investigations of the planet, including a television survey, IR and radar mapping, IR spectroscopy investigations of the composition and structure of the surface (sensing and eclipse method), and gamma spectroscopy. Plans are also being made for direct investigations of the upper atmosphere, ionosphere and magnetosphere. A balloon will be used for investigating not only the atmosphere, but also the surface of Mars.

One possible variation of balloon sounding is one in which the balloon flies during the daytime only, and descends to the planet's surface at night. Such an operation requires that the balloon consist of two spheres tethered to each other: a large, lower sphere with a plastic skin filled with Martian "air," and a small, sealed, upper sphere made of mylar film and filled with hydrogen or helium. The design parameters of the lower sphere are such that it has lift during the lighted portion of the day, as a result of the sun's rays heating the mixture of gases filling it. The application of this principle in the balloon design will make it possible to ensure the scientific instrumentation that resides in a gondola is moved considerable distances from the landing site of descent module. A drawback of the method is the random direction of the probe's movement, which is entirely dependent on wind direction. Nevertheless, available data on movement of the Martian atmosphere make it possible to calculate the possible flight trajectories of the balloon and to select the most interesting of them, which requires, however, that the balloon enter the atmosphere precisely in a predetermined region of the planet.

The survey television camera mounted in the balloon gondola ensures a photographic resolution of no less than 10 cm from an altitude 200 cm.

One of the principal technical problems associated with the Martian rover involves how to control it from a distance of millions of kilometers. For example, the Martian rover must be able to negotiate obstacles which 20-30 minutes earler were not on its path. Approximately that amount of time is required for radio signals to cover the distance from Mars to the Earth and back. A possible solution of the problem is to make the Martian rover an "expert system," giving it certain "intellectual capabilities." "Earth" will determine the work strategy, whereas the robot itself will determine the tactics for performing that work. If that means autonomy for the orbiter in solving a number of navigational problems, it means highly complex, autonomous, adaptive (i.e., adapting to conditions) control of movement for the Martian rover.

In addition to a television system, a Martian rover will obviously need to be outfitted with a laser range finder for plotting a course and controlling movement.

The navigational support of the Mars rover solves two fundamental problems: entry into the stipulated target regions and referencing the coordinates of the route.

The sequence in which the target regions are traversed will depend on the actual coordinates of the landing site. The "referencing" of the landing site and the route of the Martian rover to the terrain can be accomplished from the data of independent dead reckoning systems and astronomical observations (sun, stars) and also with a special system which includes a set of devices for raising the television cameras that are connected to the Martian rover to a height of from several tens of meters to hundreds of meters above the Martian surface. This system will make it possible to inspect a region measuring about 100 x 100 m, with a resolution better than one meter, which will enable highly precise referencing of the Martian rover position to the photomap of the Martian surface. Plans call for using three types of raising: aerostatic (balloon), aerodynamic (kite) and ballistic. The latter type is regarded as a backup in case the first two malfunction or can't be used (for example, in unfavorable weather conditions).

The range of the Martian rover should be hundreds of kilometers. The speed will be determined by the power system and is also dependent on relief of the terrain and on the scientific program to be carried out along the path of movement. Either solar cells or isotopic thermal converters can be used as the power source.

The program of scientific research for Martian rovers includes vibrational probing of deep interior of the planet in order to determine its internal structure. The Martian rover will also make it possible to obtain a large number of panoramic photographs along its path of movement. It could also be used to collect rock samples over a wide area and to depths of several meters. The collection of soil samples from the deep layers of the planet is especially important from the standpoint of its subsequent "biological" analysis, because the probability of detection of any life forms is increased. Then the Martian rover, with the collected samples, could serve as a radio beacon in an area it selects as suitable for a future lander outfitted with a return rocket for delivery of the Martian soil to the Earth.

Weather instruments will also be mounted on the Martian rover.

It must be said that the study of meteorological conditions on Mars is an important task of the first stage of planned investigations of the planet. For that very purpose, plans call for establishing a network of 10 small long-lived (more than a year) weather beacons on the Martian surface. Their principal purpose will be to make direct measurements of meteorological parameters for studying circulation of the atmosphere and for forecasting meteorological conditions for current and future missions. The advantages of such a network are the global nature of coverage, the possibility of dropping stations in particularly interesting regions (canyons, old river channels) which are inaccessible to investigation by other means, and all-season coverage (including the season of dust storms) because of their long lives.

Penetrators, in addition to their study of the physicochemical properties of the planet's soil, make it possible to obtain data on its internal structure. Several penetrators will form a network of fixed stations ensuring prolonged seismic observations.

The principal objective of the next stage of the Soviet Martian research program is the delivery of samples of Martian soil to Earth. This stage will be performed during one of the earliest "astronomical windows" after 1994. As is well known, the most sensible time to send an expedition to Mars (sensible, in terms of putting rather large payloads into a flight trajectory) is when Mars is in superior conjunction with the Earth, being situated on the opposite side of the sun.

In 1988, such a favorable moment occurred in July; that's when the Phobos station was launched to Mars. Such possibilities for making an interplanetary flight with minimal energy expenditures and over a minimal amount of time (6-8 months) will be repeated approximately each 2 years. Consequently, the delivery of soil from Mars can probably be accomplished in 1996 or 1998.

One variation for carrying out this research stage is the launching of two autonomous vehicles: the first would make a landing on the Martian surface, and the other would become its satellite. The landing vehicle must have a takeoff rocket and a small Martian rover for collecting soil at some distance from the landing site. The Martian rover would be equipped with manipulators and a soil collector.

The takeoff rocket would deliver the soil to the orbital vehicle and would dock with it, after which the samples would be reloaded into a special module that would return to the Earth. Upon approach to our planet, it would be intercepted by an orbital station.

It would be desirable to make an initial analysis of the Martian soil aboard the station. That would make possible a solution of the quarantine problem, precluding the contamination of our planet by extraterrestrial organisms, however small such a probability might be. It goes without saying that the sterilization of the space vehicle prior to its launch from the Earth is necessary in order not to transport terrestrial microbes to Mars.

In-orbit docking operations are quite advanced. However, taking into account the rigid weight limits in interplanetary flights, much work still needs to be done to develop very light docking systems and assemblies.

The next stage in the Martian research program involves the operation on the planet between the years 2000 and 2005 of large Martian rovers with a long active lifetime and a range of movement greater than a thousand kilometers. Then, perhaps in 2010, it would be possible to carry out a combined expedition with the landing of Martian rovers and the collection of soil from 2-3 places separated from one another by great distances. Finally, by 2015-2020 it would probably be possible to support the necessary conditions for a manned expedition to Mars, with the landing of cosmonauts on its surface.

The base units for implementing the Martian program are expected to be a new generation of unmanned vehicles developed in the Soviet Union: so-called highly intelligent space robots. The Phobos project represented the first practical experience in the use of these vehicles.

Even in the first stages of development of the new apparatus, its developers had the investigations of Mars in mind. For that reason, they strove for maximum continuity of the design of the vehicle itself and of its servosystems. The spacecraft are expected to be launched with the Proton rocket, which has proven its reliability.

The Martian research program takes on a different look if the new Energiya booster is used to put the payload into space. All the principal tasks of the program could be achieved with one launch. A considerably greater number of points on the planet could be investigated simultaneously with Martian rovers, balloon probes and small landers. Preliminary analyses show, in particular, that in a single launch with the Energiya booster it would be possible to deliver to Mars three Martian rovers, several cassettes with 10 weather beacons each, and a large number of penetrators. We could also remove the weight restrictions in the task of delivery of soil from Mars and return of photofilm from a near-Martian orbit. We might also be able to attempt to return soil from Phobos.

In the variation that uses the Energiya booster, the long-range Martian program looks as follows.

The first stage (1994-1996) involves global research on the surface and in the atmosphere of Mars using a number of heavy unmanned vehicles. A detailed study would be made of its most interesting surface sectors by means of remote sensing from aboard a base station in a near-circular polar orbit (altitude 200-300 km). Some of the instruments would be placed on a steerable platform.

Then the surface would be investigated by direct methods using Martian rovers, a drilling rig, penetrators and small probes; balloons would be used to study the atmosphere, whereas the internal structure of the planet would be studied by the methods of electromagnetic and seismic sounding.

One of the principal tasks of this stage in the research would be to search for the most interesting place for the landing of a manned vehicle and to collect information on Martian natural conditions.

An objective of the second stage (2000-2005) would be the in situ testing of the main elements of a manned Martian expedition. Investigation of the Martian surface is called for, with long-term study of individual regions and delivery of soil samples to the Earth. In practical terms, this would be a dress rehearsal for a manned expedition, but without a crew.

For the first time ever, apparently, an interplanetary flight will be made with a nuclear electric propulsion system. A highly important feature of such an engine is its very high gas discharge velocity. If the discharge velocity for a jet engine operating on liquid hydrogen and oxygen is about 2500 m/s, it attains 20,000-25,000 m/s for an electric engine. The electric engine requires 15-20 times less working medium than does the liquid-fuel engine. The ship's payload can be increased accordingly.

Finally, the third stage (2005-2010) would be a manned expedition to Mars.

From a technical standpoint, a manned flight to Mars today is a quite complex but entirely solvable undertaking. Whether man himself is capable of staying in space for such a lengthy period of time (a minimum of 1-1/2 years) is another question.

The experience of Soviet cosmonauts flying aboard orbital stations shows that man can satisfactorily adapt to a prolonged exposure to weightlessness and, at the end of the flight, to Earth's gravity. Yuriy Romanenko, Vladimir Titov and Musa Manarov have already "flown the distance" to Mars on the Mir station.

Work is now being carried out on development of self-contained on-board ecological systems capable of relatively prolonged functioning on the basis of closed-loop cycle of matter, with its own mechanisms of self-regulation and self-control, as in the Earth's biosphere.

However, the problem of ensuring radiation safety for the crew is more complex than on flights in near-Earth orbit. A special radiation shelter is called for on the Martian ship, but it provides no protection against heavy nuclei of galactic cosmic radiation. As indicated by preliminary estimates, during the flight the cosmonauts, because of this radiation, will receive an almost maximum permissible irradiation dose. For that reason, all "increments" (from the nuclear propulsion system, during flight through the Earth's radiation belt, or because of X-ray flares on the sun) must be precluded. Evidently, the amount of time the cosmonauts spend on the Martian surface in a light spacesuit outside the ship's protective structure must also be kept to a minimum.

Next is the problem of maintaining communications with the crew. In addition to the time required for a radio signal to traverse the great distance between the Earth and the ship, there is also another problem: disruptions of radio communications when the ship is behind the sun. Accordingly, it is important to ensure maximum autonomy of the ship and independence of the crew in their actions.

Scientific organizations and specialists of many countries, including the United States, have expressed a desire to participate in the Martian research program proposed by Soviet scientists. In particular, the question of the joint work of Soviet space vehicles in 1994 and the American Mars Observer vehicle is being studied. The American craft, for example, could receive telemetry data from Soviet balloons and Martian rovers. Equally important is the setting up of a joint ground-based network for around-the-clock reception of data from artificial Martian satellites.

The coordination of research on individual regions of the planet is of special interest. The Mars Observer spacecraft should carry a high-resolution television camera, and since its launch is planned for 1992, it could make a preliminary investigation of the regions proposed for the landing of the Martian rovers, penetrators and meteorological beacons on the Soviet 1994 mission. Later there could be an exchange of information on the meteorology of Mars, the organization of a common data bank on the atmosphere, and joint interpretation of research results. A result of this work could be, through joint efforts, the development of an engineering model of Mars for subsequent stages in its investigation.

The giant planets and their satellites have not been neglected in the Soviet space program. For example, there is an unquestionable scientific interest in investigation of the phenomenal circulatory systems on Jupiter and Saturn and of the nature of the Great Red Spot and a number of smaller spots—free long-lived vortices in the Jovian atmosphere.

Jupiter and Saturn would be best investigated with descent vehicles (atmospheric probes) and artificial satellites; Titan would be best studied with a landing module and balloon probe. The combination of two or three different vehicles on a single expedition is also possible.

The principal obectives of research on Jupiter and Saturn with a descent module are the direct measurement of atmospheric temperature, pressure, and density and of and atmospheric chemical and isotope composition; the study of the structure of the cloud layer and characteristics of aerosol particles, including an analysis of their chemical composition; the measurement of wind speed, fluxes of solar and thermal radiation; the recording of electrical phenomena in the atmosphere; and the analysis of its neutron and ion composition and its electron and ion concentrations.

Also called for is the study of the meteoric matter near the planets, the magnetic field in the magnetosphere, the energy spectrum of charged particles, the recording of planetary radio emissions, and study of the morphological characteristics of the surfaces of planetary satellites.

One of the objectives of the study of Titan involving a landing module will be the derivation of images of its surface and an analysis of its composition and mechanical properties.

A balloon probe drifting in the atmosphere of Titan will be used to measure atmospheric temperature and pressure, wind speed and direction and turbulence parameters; to investigate aerosol characteristics; and to analyze the chemical composition of the atmosphere. A television camera carried in the balloon gondola will make it possible to obtain a detailed image of the surface from an altitude of 5-6 km. The active lifetime of the balloon probe would be about 10 days.

Deep Space

The development of extra-atmospheric astronomy in the Soviet Union has proceeded in three principal directions. First, telescopes mounted on manned space vehicles—orbital complexes based on the Salyut station and Soyuz transport vessels—were used for observations. Then astronomical instruments were included as components of the complexes of scientific apparatus on unmanned multipurpose space vehicles such as artificial earth satellites of the Cosmos and Prognoz series and interplanetary stations of the Venera series. Finally, during recent years, specialized space vehicles, such as the Astron satellite, have been developed for astronomical investigations.

Astronomical instruments were already carried aboard the first orbital station of the Salyut series. They were used in making observations in the ultraviolet and gamma ranges. Work with these instruments made it possible to acquire experience with astronomical observations on manned space vehicles and to proceed to more complex experiments on subsequent flights.

Very interesting results were obtained using the Orion ultraviolet telescope-spectrometer carried aboard the Soyuz-13 spacecraft. In particular, thick chromospheres were discovered in cold stars, as well as groupings of hot stars of very low luminosity. An ultraviolet spectrogram of a planetary nebula, a gigantic gas formation with a very hot star at the center, was obtained for the first time.

The Salyut-4 orbital station carried a complex of astrophysical instruments which included a mirror X-ray telescope and the Filin telescope with slit collimators. During two expeditions on this station, observations were made of many X-ray sources—Cyg X-1, Her X-1, Cir X-1, the X-ray nova A0620-00 and others—during the course of which interesting information was obtained on the properties of these objects.

A new range of wavelengths was covered on the Salyut-6 orbital station, which carried a large submillimeter telescope with a mirror diameter of 1500 mm.

During the flight of this station, the KRT-10 (space radio telescope with a 10-m antenna) was delivered to the station in individual units and assemblies, which were then assembled by the cosmonauts.

A broad program of astrophysical experiments was also carried out on the Salyut-7 orbital station. The principal astronomical instrument of the station was an X-ray telescope (with an energy range from 2 to 30 keV) with gas proportional counters with a total area of 3000 cm^2. The telescope field of view was 3° x 3°. In 1000 s, the telescope could detect a source with an energy flux several thousand times weaker than that of the Crab nebula. Among its research results was the detection of a powerful burst of X-radiation of the active galaxy C4151.

Still another astronomical instrument on the Salyut-7 was the Yelena gamma telescope intended for measurement of the background radiation of the spacecraft structure. The data obtained using this instrument were important for setting up future experiments with large gamma telescopes.

During recent years an extensive program of observations of bursts of cosmic gamma radiation has been carried out. This phenomenon was discovered relatively recently, in the early 1970s. For a short time, not exceeding several tens of seconds, a source appears in the celestial sphere with a flux thousands of times greater than the fluxes of the brightest stationary sources in this same energy range (from several tens of thousands of electron-volts to several million electron-volts). Such events are rare; they number in the hundreds per year for the entire celestial sphere. The observation of such phenomena requires the use of omnidirectional detectors of hard X-radiation and soft γ-radiation. Many data have been obtained on space bursts of γ-radiation by means of instruments carried on the Venera unmanned interplanetary stations and the high-apogee Prognoz artificial earth satellites. The objective of these experiments (French scientists also participated in this work) was to determine the precise coordinates of gamma bursts by means of measuring the time of signal arrival at each of the spatially separated space vehicles (the triangulation method). Space vehicles of the United States and West Germany were used for this purpose, in addition to the Venera and Prognoz vehicles. Coordinates for hundreds of gamma bursts were determined with an accuracy of several minutes of arc—in one case, 5 seconds of arc.

The spectra of gamma bursts and also their time profiles were also measured. Two catalogues of spectra and profiles of gamma bursts were published on the basis of the results of this experiment.

Among the other results of extra-atmospheric astronomical observations it is necessary to mention investigations of the emission spectrum of the interplanetary medium in the ultraviolet range, which made it possible to detect solar system motion relative to the interstellar gas and to determine the physical parameters in the immediate vicinity of the sun: the density of hydrogen and helium atoms, their temperature and velocity of motion relative to the sun.

Experiments on the Prognoz satellites and Venera stations managed to survey the sky in the hydrogen and helium lines with an angular resolution of 2°. The use of an original method made it possible to measure the width of the hydrogen lines, which in turn made it possible to determine the temperature of interstellar hydrogen atoms flying through the solar system.

The specialized unmanned Astron station was put into a high-apogee orbit by the Soviet Union in March 1983.

The complex of scientific instrumentation aboard the Astron station included two large telescopes: an ultraviolet telescope-spectrometer (UVT) and an X-ray telescope-spectrometer.

The principal objective of the observations with the UVT was the collection of data on the chemical composition of stars and the interstellar medium, on the presence of a stellar wind, and on explosions and ejecta in stars, bright quasars and galaxies, as well as on other nonstationary objects. A separate television camera with a broad field of view (0.5°) was included for identification of stars.

In the experiment with the UVT, for the first time ever in the Soviet Union, a solution was found for the problem of highly precise pointing of the telescope and holding point sources of cosmic radiation in its field of view. The accuracy in pointing was on the order of tenths of a second of arc.

The area of sensitivity of the X-ray telescope was about 2000 cm^2. That is less than for the similar Filin X-ray telescope carried on the Salyut-7 orbital station. However, the Astron telescope had a considerably higher time resolution—up to three-thousandths of a second. In addition, it could be used in observing a source of X-radiation continuously up to 3 hours. Hence the main objective of the experiment was to obtain spectra and make a detailed investigation of individual sources of X-radiation. They include pulsars and remnants of supernovae, compact relativistic objects in close binary systems, active galaxies, and X-ray bursters. The accuracy in pointing and stabilization of the observatory when carrying out X-ray observations reached 2-3 minutes of arc.

Even in the initial stage of preparation of the experiment, a list of about 1000 X-ray sources and of the same number of ultraviolet sources was compiled. The list was run through a computer, which excluded approximately one-third of the sources which, for one reason or other, could not be observed from aboard the Astron during the period of its operation; the others were arranged in an observation sequence such that repointing the vehicle from one source to another would be minimal. The observations were made alternately, first with the ultraviolet telescope, then with the X-ray telescope, and then vice versa. Synchronous investigations were also made simultaneously in both ranges, which was very important for clarification of the nature of the objects under study.

As for observations in the ultraviolet range, here a search was made first of all in the stellar spectra of heavy elements such as thorium, lead and uranium. Their formation does not fit within the framework of processes known to science. It is possible that the generation of heavy elements is associated with powerful explosions in the Universe, with the interactions of two stars, including the transformation of one of them into a neutrino star. The question of how heavy elements arise is fundamental not only for astrophysics, but also for physics as a whole. A knowledge of the age of the heavy elements will help to determine specifically how star worlds are born. Thorium is gradually transformed into lead—this is the singular radioactive clock of the Universe. Consequently, by identifying the relative content of these elements it is possible to look into the distant past of our Universe. The Astron ultraviolet telescope made it possible to obtain information, however small, on the quantitative content of different elements.

A shutdown effect of the source Her X-1 was detected using the X-ray telescope, and the upper limits of the fluxes from the supernova that exploded in the galaxy M83 were determined. Fast bursters were repeatedly observed; impulses of different duration and form were observed, and a new type of burst was discovered. When a fast burster was eclipsed by the moon, a constant flux of X-radiation emanating from it was detected.

Astron demonstrated its great flexibility over the course of its lengthy operation—it could be rapidly re-aimed at new objects and could even operate in regimes which initially had not been envisaged. The observations of Halley's Comet and investigation of the supernova that exploded in late February 1987 in the Large Magellanic Cloud are examples of this.

The Astron space observatory successfully functioned in orbit for more than five and one-half years.

The Astron had still not ended its work when the new Rentgen astrophysical observatory was launched into space. Delivered into orbit aboard the Kvant module, it became part of the scientific equipment of the Mir station. This observatory is the largest single-purpose complex of those yet installed aboard Soviet orbital vehicles. The development and manufacture of apparatus for it took place in the USSR, Holland, Great Britain and West Germany, with the participation of scientific organizations and industrial enterprises of the European Space Agency.

The observatory carries four X-ray telescopes intended for handling fundamentally new tasks in high-energy astrophysics. The largest of them, the Pulsar X-1, was developed at the Space Research Institute, USSR Academy of Sciences, jointly with scientists of other scientific organizations in our country. The telescope was designed to search for and investigate galactic and extragalactic sources of hard X-radiation and to make measurements of their energy spectra. The telescope includes a special wide-angle monitor for bursts of cosmic X-radiation and γ-radiation. The large dimensions of the detector make it possible to obtain detailed spectra and to trace the development of these rare and interesting events.

Another instrument is the so-called telescope with a shadow mask—the brainchild of specialists from the Utrecht Space Research Laboratory in Holland and Birmingham University in Great Britain. The telescope operates on a new principle for producing an image of an observed object that makes it possible to achieve a resolution of several minutes of arc. At its input aperture, there is a "cover"—a shadow coding mask with square openings arranged in a given manner. The total area of the openings is close to 50% of the area of the telescope input aperture. When the telescope is "illuminated" by a parallel beam of photons from a distant source, a shadow image of the coding mask is formed in the X-radiation detector plane. Mathematical processing of the points of distribution of photon detection makes it possible to reconstruct the brightness distribution of the X-radiation in the celestial sphere, i.e., produce a "picture of it in X-rays." The position of the X-ray sources is determined with an accuracy in minutes of arc.

Still another telescope-spectrometer, the Siren-2, was developed in the space astrophysics section of the European Space Agency. A special feature of this telescope is a new principle for measuring X-ray quanta. It is based on the detection of gas scintillations: bursts of ultraviolet radiation of a definite duration corresponding to the energy of quanta. As a result, the energy resolution of the telescope is more than twice as great as the resolution of the ordinary counters that had been used until recently. For example, the telescope makes it possible to investigate the chemical composition of the hot gas in galactic clusters. This gas is exceedingly rarefied, and its temperature is tens of millions of degrees. In such a gas, the speed of sound exceeds 1000 km/s. Hundreds of galaxies move in it at subsonic and supersonic velocities.

The name of an instrument developed by West German scientists, "HEXE," is translated from the German as "witch." It was developed at the Extra-Atmospheric Physics Institute of the Max Planck Society and at Tubingen University. A special feature of this instrument is a detector of the "Fosvich" type, with oscillation of the collimators. This makes possible simultaneous measurement of the signal from the source and the background level. The telescope is intended for operation in the high-energy region.

The orbital observatory also includes Soviet instruments for control of the entire complex, for distribution of the telemetric data channels and for supplying electrical power to the scientific instruments.

In terms of its technical specifications and scientific capabilities, the space observatory will be unparalleled in the world until at least 1990. For example, the Soviet "Pulsar X-1" telescope for spectrometric research in the hard X-radiation range, which is part of the observatory, has an effective area of the detecting devices which is six times greater than that of the devices on the American satellite HEAO-3.

The Rentgen observatory has been used in making several thousands of observations, as a result of which important scientific results have been obtained. The investigations of the supernova that exploded in late February 1987 in the Large Magellanic Cloud are undoubtedly of the greatest interest.

The luminescent shell that formed as a result of the star explosion was at first so dense that it did not allow the exit of fluxes of X-radiation and γ-radiation, which lost their energy, because they were, as it were, stuck inside. But since the shell flying out in all directions at an enormous velocity, it gradually became increasingly more "transparent," and on 10 August 1987 the Rentgen observatory detected hard X-radiation. Astronomers had never before observed radiation of such a nature, with its anomalously hard spectrum. Without question this radiation was a result of the radioactive decay of cobalt nuclei being transformed into iron. In the shell, the nuclear gamma lines experience tens and hundreds of scatterings, decrease in energy and arrive at the Earth in the form of a continuous X-radiation flux with an exceedingly hard spectrum.

The radiation flux from the supernova slowly and steadily increased. The increase continued even after 98 percent of the cobalt had already decayed, which may be explained by the rapid clarification of the shell. The main objective of the continuing observations of the supernova is a search for an X-ray pulsar—a rapidly rotating magnetized neutron star formed as a result of the collapse of a blue supergiant in the neighboring galaxy.

It must be noted that the hard X-radiation observed by the Rentgen observatory had a rapidly fluctuating component with a characteristic time of several days. However, a different variability was observed in the softer range by the Japanese Ginga satellite. The different temporal behavior is indicative of the varying nature of the radiation in different energy ranges.

Among the other objects observed by the Rentgen observatory were the quasar 3C 273; the X-ray pulsar Her X-1; the well-known candidate for a black hole, Cyg X-1; a source emitting superhigh-energy gamma rays, Cyg X-3; Cep X-4; and many other objects.

Still another orbital observatory project, designated Granat, is being carried out jointly through the efforts of Soviet, French, Danish and Bulgarian scientists. The observatory was devised as an instrument complex for carrying out detailed research in a very wide range: from 3 keV to 2 MeV. That makes it possible to determine the temperature of thermal plasma in galactic clusters, X-ray pulsars and accretion disks around black holes and to identify objects where nonthermal radiation mechanisms are operative.

We recall that the American satellite observatory Einstein, which furnished scientists a mass of "fresh news" that was often completely unexpected, could operate in the soft energy range only—from 1/10 to 3 keV. The main instrument package of the Granat observatory consists of the ART-P telescope—developed by scientists of the Space Research Institute, USSR Academy of Sciences, in collaboration with other organizations—and the Soviet-French Sigma telescope.

The orbit of the Granat space observatory and the presence of a large on-board memory ensure the capability of observation sessions lasting 24 hours. That, together with the large area of the detectors, makes the observatory a record-holder with respect to sensitivity and the breadth of the scientific tasks it can handle among all the space projects which have been carried out or which have been planned for development.

The launch of the Granat observatory is planned for the same time as the launch of the West German satellite ROSAT, which has a high sensitivity in the soft X-ray range and is designed, to a large extent, to map the celestial sphere. The high accuracy that the Granat instruments will have in pinpointing the location of sources will make it possible to match them with sources on maps produced by the ROSAT satellite and with optical and radio objects. That will make it possible to investigate the spectra of weak sources in the entire range from radio waves to gamma rays.

The Granat should also be the world's largest single-purpose project for the observation of gamma bursts.

Scientists are pinning great hopes on the project Spektr-Rentgen-Gamma for solving long-range problems in extra-atmospheric astronomy. This project is evidently becoming a record-setter with respect to scales of international cooperation. Specialists from Austria, Bulgaria, Great Britain, Hungary, GDR, Denmark, Italy, Canada, Poland, Portugal, the United States, Finland, France, West Germany, Czechoslovakia, Japan and the European Space Agency are actively participating in its preparation.

The implementation of the project will make it possible to take a considerable step forward in clarifying the properties of various classes of astronomical objects and in determining the nature of many physical phenomena observed in the Universe that are still not fully understood. The instruments of the new orbital observatory should yield unique information on galactic sources of X-radiation (on "black holes" and neutron stars in binary star systems, on the remnants of bursts of supernovae, on hot interstellar gas), on supermassive black holes (they are millions or even billions of times more massive than the sun) in the cores of active galaxies, on the intergalactic gas in galactic clusters; and on the X-ray emissions of normal galaxies.

It will be possible to carry out a search for the most remote X-ray quasars: exceptionally bright formations, the radiation of each of which is equivalent to the radiation of an entire galaxy of hundreds of billions of stars. One of these quasars—OX-169—varies the brightness of its X-radiation by a factor of two in only three hours. It turns out that in size it is no larger than the solar system (it is more likely just about half the size of the solar system). The heaviest black hole of such a size would have the mass of nearly 200 million suns. What then is the source of the monstrous energy yield from quasars?

Hundreds of thousands of ultraweak X-ray sources situated at the edge of the observable Universe will be accessible to the observatory. Their detailed study will make it possible to shed additional light on the problem of the diffuse X-ray background.

The fact is that the sky does not look dark in the X-radiation range. There is background "blurred" radiation comparable to the radiation of discrete sources. It is assumed that this emits a very rarefied, hot intergalactic gas that fills all of space. If this is so, the diffuse background value can be used in estimating the mean density of the Universe and, accordingly, in judging whether our universe is "closed" or "open," whether the observed expansion of the Universe will at some time be replaced by compression. Or will it continue ad infinitum?

But does the background possibly consist of very distant and, for the time being, indistinguishable single point sources which merge into one? For that reason, the telescopes of the Spektr-Rentgen-Gamma observatory will also be directed at "empty" regions of the sky where only a background is present, in order to make counts of ultraweak X-ray sources.

Another important objective of the project will be an investigation of transient (disappearing) X-ray sources and gamma bursts.

A broad energy range, high sensitivity, spectral and angular resolution put the Spektr-Rentgen-Gamma project in the ranks of the most interesting scientific space projects of the first half of the 1990s. Within the framework of the international cooperation that has developed, this project, on the one hand, will become an important supplement to the planned launch of the ROSAT satellite and, on the other hand, a necessary logical link in the transition from the projects of the 1980s to the extremely expensive and, to some extent, ambitious projects of the 1990s of the European Space Agency—XMM—and National Aeronautics and Space Administration—USA-AXAF. The XMM project, for example, calls for the installation of four "oblique incidence" X-ray telescopes aboard a spacecraft. Indeed, X-rays cannot be focused like light in optical telescopes, and therefore they are gradually "brought together" by means of embedded ring-mirrors. Each of the telescopes will consist of 50 mirrors and have a focal length of 7.5 m.

One of the principal instruments of the Spektr-Rentgen-Gamma observatory will be the Soviet-Danish telescope-concentrator (it is installed along the main axis of the observatory), which uses oblique-incidence X-ray optics with a cone-cone configuration. The total surface area of the X-ray mirrors of the two identical telescopes is 130 m^2. The sensitivity of the telescopes is greater by a factor of 20 than the sensitivity of the apparatus which was installed on the American Einstein satellite.

The telescopes will be folded up when they are put into space, and they will opened up in orbit. The focal length of the telescopes is 8 m, and it can be changed. The angular resolution is 2'.

Soviet specialists will develop and manufacture the telescope optical system. The Soviet side is also performing all the calculations of the thermal and mechanical characteristics of the telescope, as well as the tests for correspondence to operating conditions aboard the spacecraft. Specialists from the United States, Finland and a number of other countries intend to participate in the creation of the telescope. For example, a system for replacement and precise guidance of the telescope focal detectors is being developed in Czechoslovakia.

Still another oblique-incidence telescope, the JET-X (also installed along the main axis), is intended for precise localization, spectroscopy, and image construction of weak X-ray sources with a resolution of 10". The telescope includes an optical monitor with a mirror 30 cm in diameter and a device with so-called charge feedback—a silicon microcrystal whose surface contains hundreds of thousands of sensors. Light that is collected and amplified by the mirror falls on the sensors and is converted into electrical signals proportional to the light's intensity in that part of the image. The photoplates that were always a "standard appendage" to ground-based astronomical cameras detected only seven of every 1,000 light quanta. The instrument with the charge feedback detectes 700 of every 1,000 quanta.

Thousands of stars up to the 20th and even the 21st magnitude will be accessible to the optical monitor in each observation area. That can facilitate the optical identification of X-ray objects and will make possible the synchronous investigation of their variability in the X-ray and optical ranges.

Specialists from Great Britain, Italy, the USSR, West Germany and the European Space Agency are working jointly on the development of the JET-X telescope.

These two main observatory instruments supplement each other: the Soviet-Danish telescope, thanks to the enormous collecting area of the mirrors, will be able to carry out detailed spectroscopy of relatively weak sources; whereas the JET-X telescope, as a result of its high spectral resolution, should yield record results in lengthy, deep surveys of the sky and in observations of ultraweak objects. The principal objectives of these instruments are associated with extragalactic astronomy and cosmology.

Also installed along the main axis is a Soviet-developed telescope with a coding mask; the telescope is intended for image construction and spectroscopy of sources in the hard X-ray range. Its angular resolution is 7".

A "normal incidence" telescope is being developed through the collaboration of specialists of the USSR, GDR and Great Britain for observing sources in the limiting (extreme) ultraviolet and for making investigations of the uniformity of the interstellar medium. Two identical telescopes are installed along the main axis, and two on a steerable platform. The angular resolution of the telescope is 10".

Plans also call for the steerable platform to hold yet another Soviet telescope with a coding mask, to be used for image construction and spectroscopy of bright X-ray sources and investigation of extended X-ray sources—its spatial resolution is 7"—and a Czechoslovakian oblique-incidence telescope for observing bright sources in the standard X-radiation range, with an angular resolution of 20".

A star tracker is being manufactured in Bulgaria for determining the position of the rotating platform. It will be used at the same time for optical observations of X-radiation sources.

Analysis and spectroscopy of gamma bursts of cosmic origin will be performed by a Soviet-made cosmic gamma-burst instrument.

The Spektr-Rentgen-Gamma observatory is slated to be placed into a highly elliptical orbit, with initial altitudes of 500-1000 km at perigee and 200,000 km at apogee. The duration of the working segment of the orbit will be 3-4 days. Over the course of a year, the spacecraft will twice enter the Earth's shadow for a period of no more than 3 hours.

Owing to the considerable anticipated volume of scientific information and the need for carrying out long-term investigations, the main operating mode of the instruments will be autonomous observations, with the data recorded in their own memories. The accumulated data will then be transmitted to the Earth by the radio communications system during the next communications session. In such a mode, the average duration of an observation session will be 24 hours; the number of sessions per year will be 200-250.

The vehicle will be able to observe the entire celestial sphere over the course of its working cycle. In each individual session, the space vehicle can be automatically repointed by a preassigned program to different sources that are of interest to scientists.

The Spektr-Rentgen-Gamma orbital observatory is expected to yield several billions of units of information daily. No single computer center, no one scientific group will be able to process that information completely. One solution to the problem will be to adopt a system of competitive requests for observations. That will make participation in the project accessible to all observatories, institutes and universities. Under the conditions of the cooperation agreements, the Soviet Union will receive a considerable part of the observation time for each of the instruments of the Spektr-Rentgen-Gamma observatory, and this time will be distributed among different groups of astronomers and physicists on a competitive basis, as was the case for the Einstein observatory (United States) and the IUE and EXOSAT (European Space Agency) satellites and as is planned for the Hubble space telescope.

The launch of the Spektr-Rentgen-Gamma space observatory is planned for 1993.

Gamma astronomy is also acquiring the rights of space citizenship. The inclusion of the gamma range into the circle of astronomical observations should gradually lead to a new qualitative advance in man's comprehension of world around him. One of the specific features of the gamma range that distinguishes it from the other parts of the spectrum is the enormous energy of the gamma quanta. And that promises penetration to an interaction with a great energy release in each elementary process.

Gamma quanta are generated during the interaction between high-energy particles and matter in, for example, thermonuclear reactions. Such processes evidently lie at the basis of the "vitality" of stars and bright galaxies and occur during the explosions of stars and during explosions of galactic nuclei. Gamma astronomy thus makes it possible to peek into the world of high energies, to "see" and study processes which control the world of stars and galaxies and, in the last analysis, determine the development of the Universe.

Another noteworthy feature of gamma radiation is its high penetrability. It is not affected by electromagnetic fields and propagates virtually linearly. Absorption averages no more than a tenth of a percent in any direction. In essence, the metagalaxy is transparent to such radiation. The absorption of gamma quanta is substantial only for very remote parts of the Universe. Consequently, gamma astronomy has the potential capacity for "looking" even farther than can radio astronomy and "seeing" earlier epochs in the development of the Universe.

Such special regions of the Galaxy as, for example, its center, which is hidden by the clouds of dust and gas surrounding the galactic nucleus and is therefore invisible in the optical range, should be "visible" in gamma range.

The first satellite-borne gamma telescope in which a spark chamber was used to determine the direction of arrival of gamma quanta was carried aboard the Soviet Cosmos-264 (1969). A number of important results relating to diffuse galactic gamma radiation and discrete sources were obtained on the American and West European satellites SAS-2 and COS-B and on high-altitude balloons. Today, scientists have determined rather precisely the region in which certain "gamma stars" are located. But many of them have yet to be matched with any object whatsoever in another spectral range.

Scientists are associating a new stage in the development of gamma astronomy with the placement into operation (its launch in 1989) of the world's largest space-based gamma telescope, developed by Soviet and French scientists. Polish specialists later entered into this collaboration. The telescope was given the name "Gamma-1" and will be used in carrying out research in the hardest energy range (above 50 MeV). The space observatory will also include a soft-gamma-radiation telescope and an X-ray telescope-spectrometer.

The Gamma-1 telescope, in contrast to those installed aboard earlier spacecraft, uses a wide-gap spark chamber. In the compartments of such a chamber, the spark moves along the particle track if its trajectory deviates from the vertical by no more than 20°. That improves the spatial accuracy in the determination of the coordinates of the emission source and reduces the number of spurious breakdowns that distort the observation picture.

A vidicon is used to remove the information from the telescope spark chambers. A television system measures the coordinates of the sparks and transmits data to the telemetry system. The direction of motion of the gamma quanta is determined with an accuracy to 1°.

The active lifetime of the space observatory in orbit should be no less than one year. The gamma telescope will observe a given region of the sky for a period of from a week to a month. Data will be sent from the terrestrial emissary several times a day.

Astrophysicists are placing great hopes on the further development of radio astronomy. Using radio astronomy, they intend to "see" and comprehend when and how the first galaxies, first stars, and first planetary systems were formed and determine the nature of quasars and galactic nuclei and whether they are related to large black holes. They want to know what, in general, are the principal properties of the space around us, what its mean density is, and what its evolution was like, beginning with the Big Bang. Finally, they are no less interested in determining whether there are regions of the Universe differing substantially in their patterns from ours, in seeing and investigating other planetary systems, in determining the probability of the emergence of life in various regions of the Universe, and in attempting to detect other, extraterrestrial civilizations.

Radio methods afford the possibility for investigating objects from which only the very smallest quantity of energy reaches the Earth, because of their great distance, and which also have such a low temperature that their radiation arrives only in the radio range.

However, owing to the great length of the radio waves, the resolution of radio telescopes is no better than that of the naked eye. A solution was found in the investigation of the radio emissions of space objects by way of analyzing the interference pattern created by two or more radio telescopes, with the information recorded on magnetic tapes, which are then processed on a computer using information on the current geometry of the interferometer and the coordinates of the radio source. Such a system was equivalent to an instrument with a diameter equal to the distance between the antennas.

Scientists have long been making radiointerferometry observations of the nuclei of extragalactic objects and star formation regions in the Galaxy. These observations have better resolution than other research method in any range of the electromagnetic spectrum (to 0.0004" at a wavelength of 1.35 cm). Radio observatories in the USSR, the United States, Australia, West Germany and Sweden are participating in the experiments. An interferometer with a base of Yevpatoriya-Simeiz-Pushchino has been set up.

The unique possibilities of long-range extra-atmospheric astronomical observations involving the construction of large radio telescopes in space and their spacing at distances much greater than the Earth's diameter have been investigated for the first time ever, at the Space

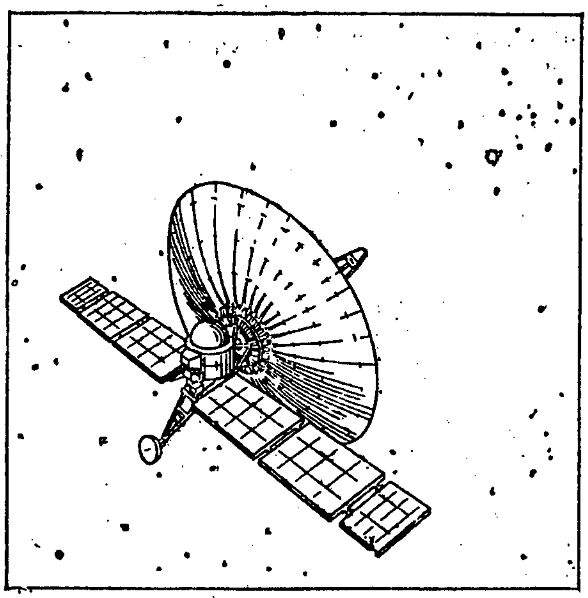

Fig. 4. Radioastron spacecraft.

Research Institute of the USSR Academy of Sciences. Such telescopes will make it possible to increase their sensitivity and angular resolution by many orders of magnitude. The first step in this direction was taken in 1979, when, at the initiative of the institute and with its participation, a space radio telescope with a 10-m antenna (the KRT-10) was deployed aboard the Salyut-6 orbital station.

Today new instruments are being developed. One of the more immediate projects on which scientists are working (it has been named "Radioastron") calls for the development of a ground-space radio system equivalent in its efficiency to a gigantic radio telescope with an antenna diameter greater than a million kilometers.

The project is slated to be implemented in three stages. In the first stage (1991-1996, "Radioastron-SM") plans call for putting a space vehicle into a so-called diurnal orbit (period of revolution, 24 hours; perigee altitude, up to 7,400 km; apogee altitude, 77,000 km). A space radio telescope with an antenna diameter of 10 m and a ground-based network of radio interferometers form a unified system, which makes it possible to achieve a resolution of up to 3 x 10^{-5} second of arc. With the selected orbital parameters, the duration of continuous measurements will reach 24 hours, and the total duration of the experiments will be two years. It will be possible to perform observations in different directions on the celestial sphere by using an orbital evolution that stems from natural factors.

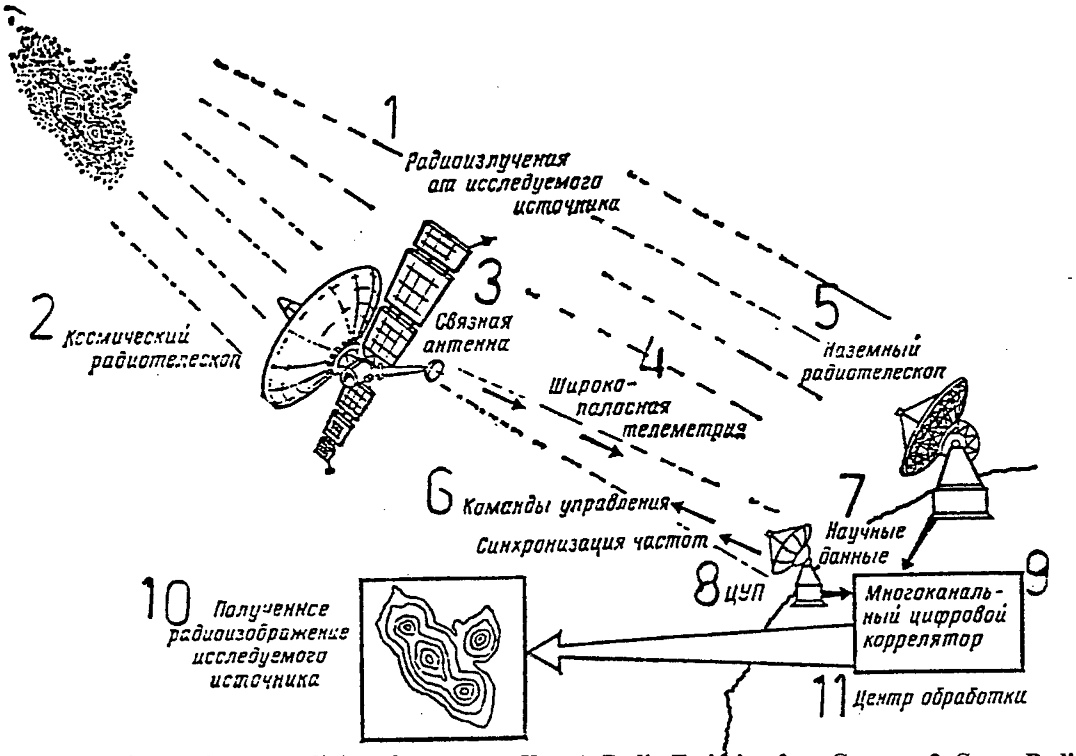

Fig. 5. Diagram of ground-space radiointerferometer.—Key: 1. Radio Emission from Source—2. Space Radiotelescope—3. Communication Antenna—4. Wideband Telemetry—5. Ground Radiotelescope—6. Control Commands and Frequency Synchronization—7. Scientific Data—8. Flight Control Center—9. Multichannel Digital Correlator—10. Received Radio Image of Investigated Source—11. Processing Center

In the second stage (1996-2000, "Radioastron-MM"), the spacecraft orbit will be chosen on the basis of the results of the work with Radioastron-SM. Finally, in the third stage (2001-2006, "Radioastron-KK"), the space aperture synthesis system will consist of three radio telescopes each with an antenna diameter of 30 m, one of which will be in a geostationary orbit, the second in an elliptical orbit with a period of revolution 27 days, and the third at the antisolar libration point (at a distance from the Earth of about 1-1/2 million kilometers). Using such a system it will be possible to construct three-dimensional images of objects in our Galaxy.

The brain center of the Radioastron project is in the Soviet Union, but the research project itself is acquiring an increasingly international character. The on-board apparatus for the Soviet space radio telescope and the data processing facilities will also be developed by a consortium of European radio observatories, the Technological University of Finland, the Australian Scientific Research Society, the Australian Radio Astronomy Observatory and the United States National Radio Astronomy Observatory.

All the largest radio telescopes in the world will operate simultaneously with the space-borne instrument. Four specialized centers are being organized for processing the anticipated enormous flow of information. These centers, outfitted with powerful computers, will be located in Western Europe, Australia, the United States and the Soviet Union.

One of the most noteworthy achievements of radio astronomy was the discovery, in 1965, of weak radiation reaching the Earth from all directions. That radiation was named relict radiation.

The Prognoz-9 high-apogee satellite was launched in the Soviet Union in 1983. The principal instrument of the scientific instrumentation package on that satellite is a highly sensitive radiometer intended for the investigation of angular fluctuations of the brightness of relict radiation at a wavelength of 8 mm.

According to currently accepted theory, our Universe is expanding. The galaxies and their clusters are swiftly moving away from one another as the space between them expands. And that may mean that at some given moment in time in the distant past, all the matter and all the energy of the Universe were concentrated in a single "point." Then there was an explosion and dispersion... Hence the name "Big Bang" theory.

In the first instants after the explosion, the temperature of the matter could be expressed by a 1 with 32 zeroes behind it. That initial plasma consisted of helium protons and ions and electrons continuously emitting, scattering and again absorbing photons. About a million years after the beginning of the expansion, the temperature of the plasma and the radiation had fallen all the way to 4000°. The electrons were joined to the nuclei of atoms, the matter in its mass was transformed into a mixture of hydrogen and helium atoms, and the Universe in a very short time became transparent to radiation.

With further expansion, the radiation that had come "unglued" from matter became increasingly colder. Now its temperature is only 3° above absolute zero. However, the nature of the radiation and its spectrum remain as a relict, like a "memory" of an early period in evolution of the Universe.

Studying relict radiation, however, turned out to be very difficult because there is a great deal of noise. As a result, there was a total of only 24 hours of "clean" observation time over 15 years or so of research.

The "clean" observation time with the Prognoz-9 radiometer (Relikt-1 project) amounted to a half-year. In addition, a very high telescope sensitivity was achieved—it could distinguish two points on the celestial sphere if their temperature differed by only tenths of a degree. The sensitivity of the radiometer developed by Soviet scientists, judging from reports in the foreign press, is twice that of a similar instrument on the American satellite COBE (Cosmos Background Explorer), whose launch is not planned until 1989.

Prognoz-9 confirmed the highly uniform distribution of the brightness of relict radiation in the sky. No other effects—not even weak effects whose existence is envisaged in other models of the Universe—have been discovered, which already places these models in question.

Today Soviet scientists are preparing a new project, Relikt-2, for investigations of the large-scale anisotropy of relict radiation. An essential feature of the experiment is the cooling of the radiation detector and antenna. That will make it possible to better the sensitivity achieved in the Relikt-1 project by a factor of 3-4.

With such a high sensitivity, the main source of systematic noise is the radiothermal emissions of the Sun, Earth and Moon. In order to eliminate that noise, the space vehicle will be placed into the vicinity of the libration point situated at a distance of 1.5 million kilometers from the Earth.

In the Aelita experiment, planned for the mid-1990s, the apparatus will no longer be cooled by the radiation method, but by a special cryogenic system—liquid neon and superfluid helium—and for profoundly cooled bolometers, by a cyclically operating adsorption-type cryogenic refrigerator. The sensitivity of the apparatus in this case will reach approximately 10^{-5}K.

According to calculations, the expected operational life of the cryogenic system will be 3-4 years.

The objectives of the Aelita project include observations of the "cold" matter in our galaxy and other galaxies and investigation of inhomogeneities of the cosmological relict background. Data on "cold" matter—dust and molecular clouds—will make it possible to clarify the processes of star formation and the evolution of interstellar matter and galaxies in general. Investigation of inhomogeneities of relict radiation—in particular its scattering on the gas of galactic clusters—will yield important information on the early stages of the existence of the Universe. In addition to research in "super-deep" space, this experiment may also make a major contribution to the study of our solar system, especially of comets and the atmospheres of the giant planets.

In addition to Soviet scientists, their colleagues from Italy will participate in the Aelita project.

Man Makes Himself at Home in Space

As of 1 December 1988, a total of 208 persons had made space flights. They were, primarily, citizens of the USSR and the United States (22 cosmonauts were from other countries). A total of 121 individuals had made one flight; 55, two flights; 26, three flights; 4, four flights; 1, five flights; and 1, six flights. Among those flights, there were 46 brief flights (14 days or less) in the USSR and 53 in the United States; there were 11 of intermediate duration (from 14 to 120 days) in the USSR and 3 in the United States. Prolonged flights (more than 120 days) had been made only by the Soviet Union—a total of 12,361 space days had been logged by Valeriy Ryumin's group (in two flights). It seemed that this record would not be broken soon. But Yuriy Romanenko, on three flights, logged 430 days. It was him who, until recently, owned the new record for the longest continuous stay in space. Today, as is well known, that record has been surpassed by Vladimir Titov and Musa Manarov.

The indisputable fact that man's fundamental mastery of near-Earth space is possible only with the construction of long-lived orbital stations is becoming increasingly evident. Eight orbital stations have been launched in the Soviet Union since April 1971. Their successful operation made it possible to determine the principal directions in the development of manned flights and to develop a strategy for the use of space-based research laboratories in the interests of science and for the solution of applied problems.

If Salyut-6, which was the first station in history to be equipped with two docks, was a second-generation station, the Mir scientific research complex can rightfully be considered a third-generation multipurpose space laboratory. It represents a qualitatively new stage in manned facilities designed for fundamentally new space research technologies.

In contrast to the Salyut-6 and Salyut-7, the Mir station has 6 docking facilities. Thus, a total of 5 units can be docked to the forward end of the station alone—a transport craft and four modules.

It is quite clear that the principle of adding scientific, technical, and production equipment onto the station through individually delivered modules, plus especially the possibility of replacing them as new research tasks come about, greatly broadens the range of the diverse scientific investigations that can be carried out in orbit. Each module is outfitted with specific gear and equipment that suit its purpose—for example, to carry out astronomical investigations, perform production experiments and produce new materials in weightlessness, or make remote investigations of the Earth from space. In short, laboratories, workshops, observatories, greenhouses, etc., can be set up in the modules.

The first such module, with an X-ray astrophysical observatory on board, has been operating as part of the Mir orbital station since March 1987. Preparations are being made for the launch of new modules—geophysical, production, and biological modules. With respect to the main purpose of the geophysical module, the term "astronomy in reverse" is entirely applicable. The scientific instruments carried aboard it will not be aimed at distant space objects, but instead at our planet. They will be used in remote sounding of the Earth from space for the purpose of studying natural resources, ensuring reliable monitoring of the environment, and forecasting of weather and short-term climatic changes.

The planned research program takes in a broad range of problems. In particular, the scientists of the socialist countries participating in the Intercosmos program have drawn up the Geosistema project whose purpose is the further development of means and methods for remote determination of different physical parameters of the atmosphere and the Earth's surface, including the surface of the ocean and inland water bodies.

One of the sections of the Geosistema project involves research over subsatellite test ranges outfitted with apparatus for measuring surface and atmospheric characteristics determined simultaneously from aboard a space vehicle by remote methods. In the GDR, for example, the Leipzig-Halle test range will be used for this purpose, as will the Caribe-Intercosmos test range, in Cuba.

As for the space technology, it involves the research areas that are best prepared today for changeover to a "modular regime" of opertion. The urgency itself of this area is related to the prospects for the development of new materials unique in their physicochemical properties and for the use of that development to set up industrial production in space.

When a production module become part of Mir, setting up the experimental production of small batches of certain materials will evidently become possible. Soviet scientists and specialists from the socialist countries have developed a number of production units for performing such work. Among them is the Soviet-Czechoslovakian Kristallizator apparatus designed for performing production research aboard an orbital station and producing materials on a semi-industrial scale. The apparatus is equipped with a microprocessor and can operate in an automatic mode run by a program recorded on magnetic tape. The crew performes preventive maintenance and, if need be, repair of the equipment.

To be sure, the first stage will involve only the production of certain types of materials, the demand for which is no

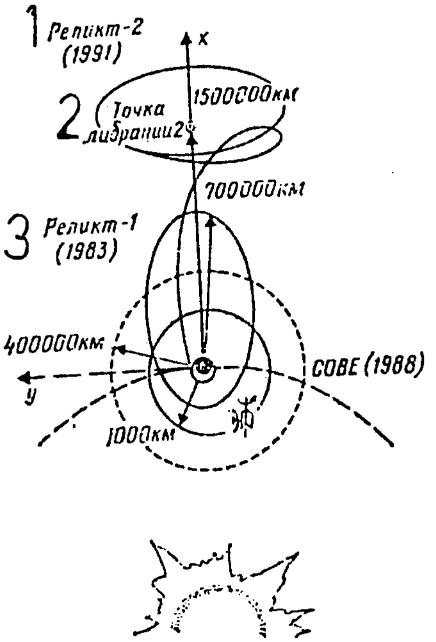

Fig. 6. Orbit of space vehicle in Relikt-2 project in vicinity of libration center L_2.—Key: 1. Relikt-2 (1991)—2. Libration Point 2—3. Rellike-1 (1983)

more than tens of kilograms per year, but the cost of each kilogram will be high. Those materials will include, in particular, large semiconductor crystals, certain biological preparations, and high-quality glasses for lasers. According to recent estimates, the cost of terrestrial production for most of these materials is comparable to or even greater than the cost of delivery of raw material into orbit and return of the final product to the Earth.

The principal purpose of the biological module will be to carry out research related to solution of the problems involved in man's prolonged stay in space and to preparation for interplanetary flights. The biomodule is expected to consist of four main compartments: a sanitary-airlock compartment, a scientific research compartment, an experimental-operational compartment, and a compartment for housing the biological subjects.

An increase in the scales of space activity will require improved transport operations. The flow of cargo between Earth and Space to meet the needs of orbital complexes for power, replaceable elements, and scientific instruments and apparatus will increase substantially. Here definite hopes rest on the development of a reusable system.

Another problem is the transfer of spacecraft from one orbit to another. For the time being, it is too expensive. For that reason it, is necessary to develop reusable "tugs" with electric jet engines whose power would be supplied by solar cells.

Such "tugs" could be used to move an orbital station into, for example, a sun-synchronous orbit, which is of interest in that the conditions for illumination of the subsatellite zone on the Earth's surface remain constant for a long period. Owing to the Earth's diurnal rotation different sectors of the Earth's surface fall into this zone, but the pattern of change of solar altitude above them is repeated from revolution to revolution. An operational mode of uniform illumination for all the on-board observation equipment—spectrometric, photographic, and television equipment—is thereby ensured. The range of research could be broad—from visual observations of land and sea surfaces to implementation of narrow-focus scientific programs in meteorology, ecology, geology, etc.

With each passing year, space research is opening up ever newer horizons for the progress of science, technology and production. What has been achieved today represents only the first steps. Manned spacecraft will, to an ever greater extent, serve not only as a means for broadening the sphere of research, but also as a means for broadening the sphere of life. It is natural here that man's further mastery of space involves solution of complex biomedical problems such as, for example, the physiology associated with man's prolonged stay in space and the development of closed-cycle life-support systems.

The future will see the the construction of spacecraft which, equipped with gear for communications over superlong distances and with advanced navigational instruments and life-support systems, will make interplanetary travel spanning years possible.

Since the launch of the world's first artificial earth satellite, the Soviet Union has repeatedly declared that it is devoting its space achievements to all of mankind. That course is being held consistently and without deviation.

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