

SOVIET SPACE SCIENCE

In the next few years the USSR will send landing craft to Mars and its moon Phobos, place gamma-ray and x-ray observatories in Earth orbit and launch a 10-meter radiotelescope as orbiting partner to an Earth-based instrument for interferometry.

Roald Z. Sagdeev

The physicist Lev Artsimovich once defined science as the way scientists satisfy their curiosity at the expense of the nation. Space studies are in no way the cheapest source of satisfaction, so making decisions about the main trends of space science and about the priorities of these studies is a heavy responsibility.

We in the Soviet space program recently had a chance to discuss our approach to space studies at the International Space Forum, held in Moscow in October 1987 (see *PHYSICS TODAY*, February, page 69). There we told scientists from 35 countries that we are firmly convinced that investigations in space should not become an area of competition (and economic aspects are not the least important factor here). In fact, space studies appear to be the most feasible area for international cooperation as well as the area in which international cooperation should pay off best. The Mars rover shown in figure 1 is being developed for a mission on which the Soviet Union seeks international cooperation.

International cooperation starts long before joint projects and the integration of instruments. It starts, in effect, when *glasnost* is present in discussions of plans by members of the international community. Openness helps prevent redundancy. In space astronomy, for example, early planning for the Hubble ultraviolet telescope by US scientists gave us time to think again and choose our own way to expand the spectral range of astronomical measurements.

In this article I will discuss some of our projects in

space astronomy, Solar System physics and space plasma physics, which are the three areas of highest priority in our space program.

High-energy astrophysics

We expect to learn much from a long-term program in high-energy astrophysics. On 10 August 1987 the international orbital x-ray observatory Röntgen, which is on board the Kvant ("Quantum") module docked to the Mir ("Peace") space station, discovered hard x-radiation from supernova 1987a in the Large Magellanic Cloud (see *PHYSICS TODAY*, January, page 20). The spectrum of this source, shown in figure 2, shows it to be the hardest x-ray source yet observed. In the standard 2–15-keV x-ray band, where the Japanese satellite Ginga made measurements, the supernova was 1000 times weaker than the Crab Nebula. In the 300–500-keV band, where the Soviet instrument Pulsar X-1 made measurements, the source is only several times weaker than the Crab. The hard x-ray radiation is leaking toward us through an expanding envelope, which has a mass more than ten times that of the Sun, and without any doubt these x rays are associated with gamma rays produced as cobalt-56 decays into iron. By February 1988 more than 95% of the cobalt nuclei had decayed, but we see the radiation flux growing nevertheless as the expanding supernova shell becomes less dense and more transparent.

Röntgen, whose development involved groups from the Federal Republic of Germany, the UK, The Netherlands and the European Space Agency, continues its observations. Its objects of observation include quasar 3C273, active galactic nuclei, x-ray pulsars and black hole candidates. The observatory's goal, however, is to see whether or not an intense x-ray-emitting pulsar was born after the star explosion in the Large Magellanic Cloud.

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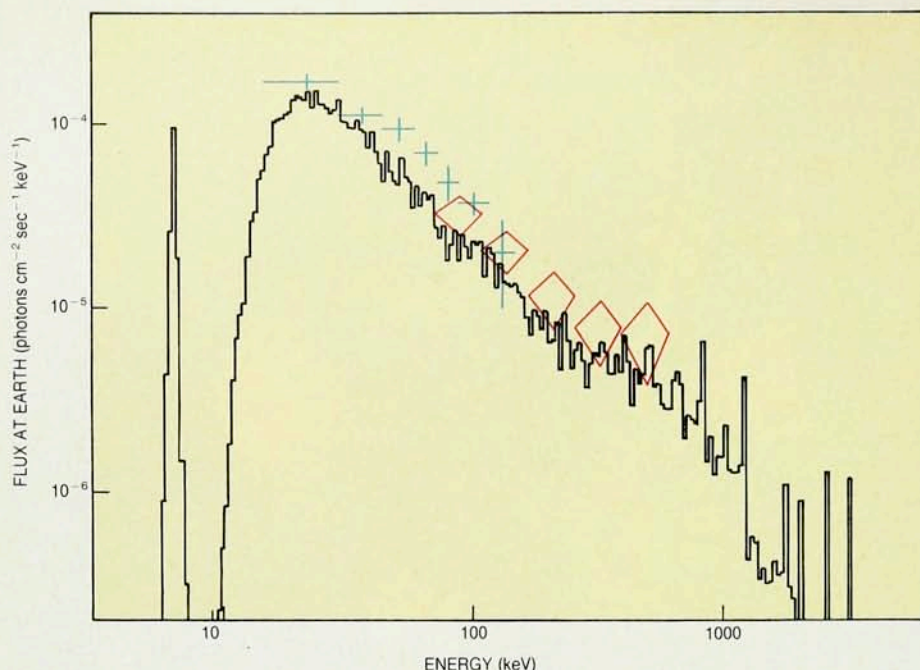
Mars rover during testing. The small vehicle is under development for a mission to the planet in 1994. It would travel several tens of kilometers and would sample soil to depths of several meters. **Figure 1**

In 1989 we plan to launch a new spacecraft for gamma-ray and x-ray astronomy—Granat—which may be able to help Kvant answer this question. With its 200 000-km-apogee orbit, Granat will spend three days out of four beyond Earth's magnetosphere and conduct continuous observations against the relatively permanent background of high-energy charged particles. The SIGMA telescope on board Granat is the product of our cooperation with the French Space Center in Toulouse and the Nuclear Center in Saclay. This 1-ton instrument will image the sky in hard x rays and soft gamma rays. The Soviet instruments ART-P and ART-S on Granat will provide images, energy spectra and timing in the 3–100-keV spectral band. The Granat spacecraft will also carry many instruments to investigate cosmic gamma-ray bursts in the 2-keV to 100-MeV energy range. Groups from Bulgaria, France and Denmark took part in the development of a set of instruments to measure bursts.

Soviet-French instruments to study gamma-ray bursts are mounted on the two Phobos spacecraft scheduled to be launched to the Mars moon of the same name in the summer of 1988. The millions of kilometers from Earth to these spacecraft—they will be about 1 astronomical unit from Kvant, Ginga, the American Solar Maximum Mission satellite and possibly Granat—will provide a favorable setup for accurate localization of cosmic gamma-ray bursts.

Our next large-scale project in high-energy astrophysics is the Spektr-X- γ satellite. This instrument should solve some problems of extra-Galactic astronomy and cosmology. Our plan is to launch by the end of 1992 a satellite with a 2.5-ton payload into an elliptic orbit with a period of 4 days and an apogee of 200 000 km. The satellite is under development at the Babakin Center—our principal contractor for unmanned spacecraft—and will probably have two large x-ray telescopes with grazing-incidence optics and 8-m focal lengths. The x-ray mirrors are likely to be cones made of a nickel-covered aluminum foil. The cone-to-cone-type optics give an angular resolution of about 2 minutes of arc within a $1^\circ \times 1^\circ$ field. We are developing these telescopes with the Danish Institute for Space Research. The foil mirrors are thin and light, so that 130 concentric cones can be nested, with the diameter of the outer cone being 60 cm. The entire mirror surface area of the two telescopes will reach 130 m², while the effective area that will receive the x-ray flux could be up to 3000–4000 cm².

These instruments should permit us to observe the K lines of highly ionized (hydrogen- or helium-like) iron ions with photon energies of 6.7–6.9 keV, which are well identified in the spectra of hot intergalactic gas in clusters of galaxies and generally typical of a low-density plasma with a normal cosmic abundance at temperatures of 1–30 keV. We expect to learn much from estimates of the



Supernova spectrum taken in January 1988. The crosses represent data from the West German high-energy x-ray experiment in the Röntgen x-ray observatory, which is on board the Kvant module docked to the Mir space station. The diamonds represent data from Pulsar X-1, the Soviet instrument in the Röntgen observatory. The histogram is the result of a Monte Carlo calculation of x rays emerging from the supernova envelope due to gamma rays emitted by cobalt-56 inside the envelope. **Figure 2**

redshifts of the 6.7-keV x-ray lines of iron in distant clusters of galaxies.

For cosmological studies, we are thinking about including in the payload of the Spektr-X-γ satellite two much smaller x-ray grazing-incidence telescopes with one-tenth the effective area but with a higher angular resolution of 10–30 arcsec. Like teams from the FRG, the UK, Italy and ESA, we believe that such telescopes, which are also sensitive up to 10 keV, could give better insight into a series of interesting problems of cosmology and Galactic and extra-Galactic astronomy. These telescopes would give the scientific teams preparing the giant European x-ray astronomy project XMM—the X-Ray Multimirror Telescope—important experience through work with telescopes that have a collecting area one-twentieth that of the telescopes they are developing for XMM. Even such small telescopes can observe hundreds of thousands of x-ray sources in the sky.

In the extreme-ultraviolet region—one of the few that astronomers have not yet studied thoroughly—one can use multilayer normal-incidence mirrors. We are developing telescopes with such mirrors in cooperation with several UK institutes, the Applied Physics Institute in Gorki and the Lebedev Institute of Physics in Moscow.

We plan to mount some of them on a rotating platform together with a small grazing-incidence x-ray telescope developed in cooperation with the German Democratic Republic and Czechoslovakia. A Soviet coded-mask x-ray telescope and an optical monitor developed with Bulgarian scientists will also be included. This set of instruments will help monitor “targets of opportunity” and conduct detailed investigations of relatively bright sources that appear suddenly in the sky—objects such as supernova 1987a and transient x-ray sources. This suggests the use of an “all-sky monitor” to detect the appearance of a target of opportunity, and of gamma-burst detectors to give physicists interesting and puzzling data at a relatively low cost.

Experimental cosmology

The last decade has seen the rapid advancement of experimental cosmology. However, after more than two

decades of studies of the anisotropy in the microwave background radiation, nothing has been detected experimentally except the dipole component that gives us information about our motion relative to the microwave background. The absence of a noticeable anisotropy probably implies that at the moment of recombination—that is, at the time of the formation of neutral species—the universe was quite uniform. This raises the question of how the structure of the universe that we observe today developed from almost uniform matter at the moment of recombination.

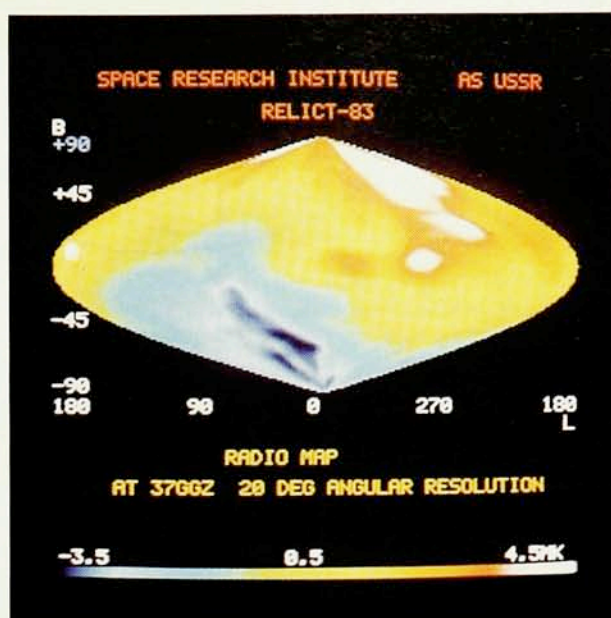
Our understanding of the evolution of the universe depends on the nature of the missing mass. If this mass comprises neutrinos with finite rest masses, their “clustering” becomes possible only at a sufficiently large total mass—on the order of 10^{16} solar masses. Superclusters of galaxies could have such masses. Smaller formations in the universe might then develop due to hydrodynamic fragmentation during the gravitational contraction of superclusters. In the model based on axions, objects with small masses of about $10^5 M_{\odot}$ form first and then cluster and form larger structures. These two scenarios give different predictions for the angular spectrum and amplitude of the anisotropy in the microwave background.

Investigations of anisotropy in the microwave background radiation meet with enormous experimental difficulties because of the extremely low level of fluctuations predicted by contemporary cosmological models— $\Delta T/T$ is less than $2-3 \times 10^{-6}$ —and because of interfering background radiation from our Galaxy.

From the surface of the Earth we cannot study large-scale anisotropy because the relic photons come to us only after they have passed through the atmosphere. Fluctuations due to nonuniformity in the distribution of atmospheric water vapor are several orders of magnitude larger than the sought-for cosmological fluctuations. Hence, with the Relict-1 experiment in 1983, our institute began space investigations of the large-scale anisotropy of the background radiation.

Scientists at IKI compiled a radio brightness map for most of the celestial sphere. The map, shown in figure 3, has an angular resolution of 5.8° and a temperature

Radio sky map. This map of 8-mm microwave radiation was compiled from the 1983 Soviet Relict-1 experiment on the Prognoz-9 satellite. The 2.8 kelvin constant component has been subtracted. What remains is dominated by a 3-millikelvin component. The map uses the Galactic system of coordinates; the Milky Way is along the equator and the center of the Galaxy is at the center of the map. The emission along the Milky Way is brightest in the vicinity of the Galactic center. **Figure 3**



resolution of 0.5 mK. Parameters of the dipole component of the anisotropy were updated in 1987, and a dispersion analysis method was developed on the assumption of *a priori* information about the spectrum of primordial fluctuations. The method yielded the most stringent limitation on the anisotropy in the microwave background radiation. For models with the Zel'dovich spectrum of the initial density of matter and perturbations of metrics, the upper limit on the quadrupole component of the radiation is $(\Delta T/T)_2 < 1.6 \times 10^{-5}$ at a confidence level of 95%.

Radiometers with much better sensitivities and broader frequency ranges are scheduled for launch in 1992. Figure 4 illustrates the required orbits. We hope that the predicted high sensitivity of the Relict-2 experiment will lead to new information needed to understand the large-scale structure, history and future of our universe.

Radioastronomy from space

IKI has long housed partisans of the very-long-baseline interferometry approach to radioastronomy. It was natural, then, for us to dream about its implementation in space. It is now fair to say that we are ready to develop this field of study.

Radio interferometry permits reconstruction of images and determination of the precise coordinates of celestial objects, and even of their distances and three-dimensional structures. The larger the interferometer base and the shorter the wavelength, the more accurate the method.

Another aspect of radio interferometry is measurement of radio emission scintillations, which are spectrally and temporally modulated radio emissions from celestial sources. The modulation is the result of interference between rays that traverse slightly different paths through the interstellar medium because of scattering by small fluctuations in the interstellar electron density. In essence, this method complements radio interferometry. Both methods can be used concurrently, allowing one to study the structure of the source in the whole spectrum as well as the structure of the medium in which cosmic radio waves propagate.

The first space radiotelescope, SRT-10, was on board the Salyut-6 orbital station and was deployed in near-Earth orbit back in 1979. This 10-meter telescope observed the radio emission of space sources in the radiometric mode—that is, it measured only the energy fluxes of the sources. The first successful radio interferometric measurements of astronomical radio sources with

the help of a receiving antenna on board a satellite were carried out in 1986 by American radioastronomers using the Tracking and Data Relay Satellite to study the brightest sources at a wavelength of 13 cm.

These first radioastronomy experiments in space demonstrated the feasibility of deploying and controlling large antenna structures in space as well as the feasibility of employing VLBI and scintillation methods with a space radiotelescope. A ground-space radio interferometer and scintillometer (figure 5) will be a tool to study the structure of compact sources of radio emission with a high angular resolution of about 10^{-6} arcsec even in the first experiment.

The following objects are to be studied: nuclei of active galaxies and quasars; galactic relativistic objects such as neutron stars, pulsars and the vicinities of black holes; flare stars and stars with matter outflow; space masers in regions where stars and planetary systems are forming; the center of our Galaxy; and the interstellar medium.

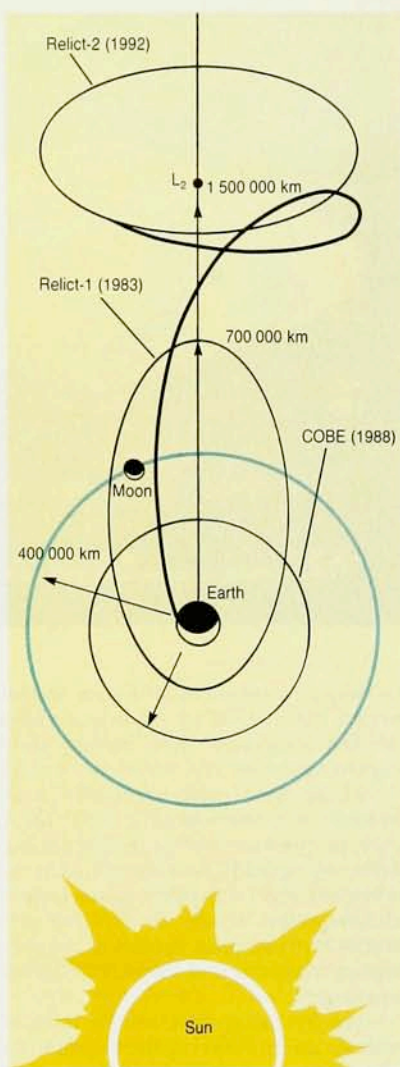
Specifically, we are planning the following projects: Radioastron-cm (1992–96), Radioastron-mm (1996–2000) and Radioastron S-S (2001–03), which is a space-space system for radio interferometry.

The Radioastron-cm and Radioastron-mm instruments will be on board spacecraft of the Spektr series, which will also carry experiments in high-energy astrophysics. The Radioastron orbit will have a period of 24 hours, a perigee of up to 7400 km, an apogee of 77 000 km and an inclination of 65°.

Radioastron S-S will consist of three 30-m-diameter radiotelescopes in space. One of the telescopes will be in a geostationary orbit; another will have an elliptic orbit with a period of 27 days; the third will orbit the antisolar point of libration, which is one of the five Lagrange points of equilibrium in the Sun–Earth–Moon dynamic system and is about 1.5 million kilometers from Earth. Such an aperture synthesis system should also solve another important problem: building three-dimensional images of objects in our Galaxy.

Venus

Until recently our Solar System program gave priority to the study of Venus. We began studying this planet with the help of space vehicles more than 25 years ago, and



Orbits for spacecraft studying large-scale anisotropy in the microwave background radiation. The Soviet Relict-2 spacecraft is to orbit the libration center L_2 , which is about 1.5×10^6 km from Earth on the side away from the Sun. COBE—the Cosmic Background Explorer—is a NASA project. **Figure 4**

struments detected the fine structure of cloud stratification as well.

The dynamics of Venus's atmosphere was studied by highly accurate tracking from the surface of Earth of the drift of balloons jettisoned into Venus's atmosphere from the Vega spacecraft. The American Deep Space Network helped greatly in tracking the balloons, which were the first to be deployed in the atmosphere of another planet. The balloon experiments measured mean velocities of the zonal wind as a function of height, detected very strong turbulence and established that air masses with appreciably different temperatures can coexist for a long time.

Halley's comet

The investigation of Halley's comet represented the first diversification of our planetary program. Studies of comets and asteroids are of particular interest because of the unique possibility such experiments offer to get to the primordial material from which our Solar System was made. Small bodies of the Solar System, such as comets and asteroids, by virtue of their size do not undergo internal heating and endogenic tectonic activity when they contain the usual amount of radioactive material. These bodies therefore represent the initial primordial material of the protoplanetary cloud from which the planets of the Solar System formed. The 1986 Vega project was part of the wide international program of studies of Halley's comet, a program that included the experiments on board the Giotto, Planet-A and Suisei spacecraft.

The most interesting data came from the comet's nucleus. For the first time the nucleus was detected as a spatially resolved object (see the cover of this issue). This permitted determination of the shape, size, mass and other characteristics of the nucleus. The nucleus's unexpectedly low albedo—about 0.04—was a surprise. The nucleus seems to be covered by a crust of high-polymeric organic material, making it one of the darkest bodies in the Solar System. Dust emanates in narrow jets from several active areas on the illuminated side of the nucleus.

The chemical experiments yielded significant data too. The basic components of the inner coma are water vapor, carbonic oxides and dioxides, organic molecules and dust. An analysis of dust particles showed conclusively the presence of complex organic compounds. All the data acquired on the dust allow the conclusion that these compounds are of interstellar origin.

Indeed, the mass of Halley's comet seems to be typical of short-period comets and therefore gives an approximate lower bound for the average mass of a "new" comet coming in from the cloud of comets hypothesized by Jan Oort in 1950. These comets are thought to be at heliocentric distances of 20 000–50 000 AU. The mass estimates for Halley's comet have led to re-estimates of the mass of the halo of the Oort cloud, which now appears to be on the order of 100 Earth masses. If the cloud has a dense inner core—the so-called inner Oort cloud—then the cloud's mass would be on the order of 10^3 – 10^4 Earth masses. Because such great masses could not be ejected by

have launched 18 spacecraft to the planet in this period. We have been asked at times whether we are doomed to fly to Venus. Actually, we have simply followed a program that developed methodically, step by step. We succeeded in obtaining, first, black-and-white images, and then color images of the planet's surface at spacecraft landing sites. Landing craft have determined *in situ* the elemental composition of the soil, a rather difficult task technologically. The use of side-looking radar made it possible to get a radio image of the planet's surface and to determine typical morphological features.

Our program gave much attention to the study of the atmosphere and cloud layer of Venus. Experiments measured anomalies in the composition of Venus's atmosphere, unusual isotopic ratios of noble gases in the atmosphere, concentrations of minor impurities, the anomalously low water vapor content of the atmosphere, the night glow of the troposphere and the thermal balance. All these data helped to develop a fairly complete model of the planetary atmosphere on the one hand, and to demonstrate the dramatic difference in the processes of formation and evolution between Venus and Earth on the other.

As for Venus's cloud layer, direct experiments proved for the first time the presence of sulfuric acid in the aerosol phase. We also established that the aerosol includes elemental sulfur, chlorine and phosphorus. In-

planetary perturbations from the Uranus-Neptune zone to the Oort cloud, the cometary nuclei must have formed in the periphery of the protosolar nebula. As cosmochemical data have shown, this formation could occur no closer to the Sun than 100 AU. Comet formation *in situ* or at considerably remote heliocentric distances in the rotating protosolar disc means that the core and halo of the Oort cloud should conserve practically all of their initial angular momenta. In this case practically all the angular momentum of the Solar System is concentrated in the core of the Oort cloud, if there is a core. If there is only a halo, then most of the angular momentum of the Solar System is concentrated there, and its value is an order of magnitude higher than the present angular momentum of the whole planetary system.

Martian moon and asteroids

After comets, asteroids are the next objective for study. But a spacecraft flying rapidly by an asteroid is just stealing a brief kiss. If the Martian satellite Phobos is a trapped asteroid, the Phobos probe we are developing now will be the lucky first probe to have a long rendezvous with such an object.

Two spacecraft in the Phobos project are scheduled for launch on different days in mid-1988. Approximately 200 days after launch, the spacecraft will reach the vicinity of Mars and transfer to an intermediate orbit. One of the objectives of the mission is to study Phobos from a space

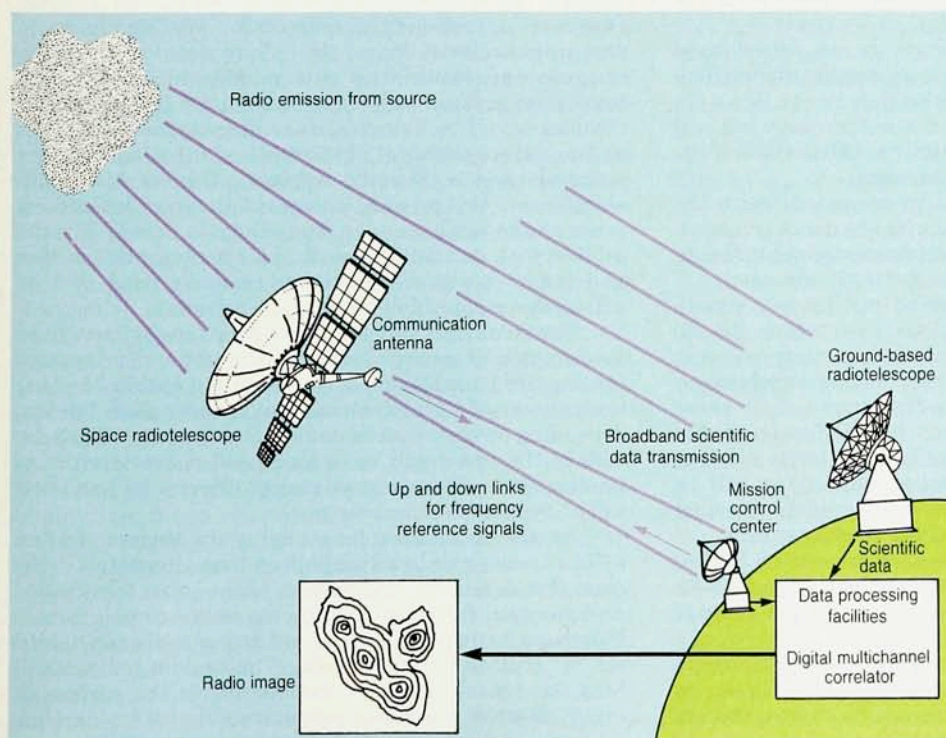
vehicle hovering over its surface at a height of about 50 m. To this end, the project envisages changing each Martian artificial satellite's orbit to put it in a circular orbit with parameters close to those of Phobos's orbit.

While the spacecraft is hovering over Phobos's surface at a height of 30–80 m, its relative velocity will be 2–5 m/sec. At this stage of the mission two small probes will separate from the vehicle and land on the surface. One of the probes is a long-term autonomous station; the other is a rover. Each has its own merits: the station has a long lifetime and many scientific payloads, while the rover can examine a larger area.

One of the most interesting and sophisticated experiments to study Phobos will be a remote laser mass spectrometric analysis of the soil. The experiment will work as follows: A laser beam focused to a spot 1 mm in diameter on Phobos's surface will deposit an energy of about 1 joule in about 10^{-8} sec, causing an explosion-like evaporation and ionization of matter. Some of the ions will reach the mass spectrometer. Figure 6a is a schematic diagram of this experiment.

In the other active experiment the spacecraft will inject an ion beam into the surface and measure the mass spectra of secondary ions knocked out. These spectra will be recorded by the quadrupole type of mass analyzer. Figure 6b is a schematic diagram of this experiment.

The spacecraft will carry a videospectrometric system for imaging the surface of Phobos and measuring its



Ground-space radio interferometry scheme. A series of projects starting in the early 1990s would study the structure of compact radio sources. **Figure 5**

spectral characteristics. The system includes three television cameras and a spectrometer. The cameras will survey the surface in three spectral bands, producing multispectral images. The system will be able to resolve details as small as 6 cm on the surface at the closest encounter with Phobos.

The topography, underlying structure and electrophysical properties of Phobos's soil will be studied with the help of radio sounding from the spacecraft. A special radar system was developed for this experiment. The sounding depth depends on the signal frequency and the soil's electrophysical characteristics, but could reach several tens or even hundreds of meters.

Infrared instruments sensitive in the 0.3–50-micron range will study the thermal and reflecting properties of the Phobos surface as well as its mineralogical composition. The infrared experiment features a radiometer, a photometer and a spectrometer that work together for simultaneous measurements.

The program also envisages two experiments for studying Phobos with remote techniques. One will investigate neutron emission from Phobos's surface to determine the bound water content and to estimate the abundances of elements that are anomalous absorbers of neutrons. The neutrons emitted from the surface come from nuclear reactions induced by Galactic and solar cosmic rays. The other experiment will spectrometrically study the gamma emission of the surfaces of Phobos and Mars.

The basic objective of the Phobos landing station, drawn in figure 7, is to perform scientific experiments that require much time. The planned active lifetime of the station is about a year.

Above all, the Phobos experiments are experiments on celestial mechanics. Phobos is gradually approaching Mars due to tidal frictional forces on that planet. If we pin down the magnitude of this effect more precisely, we will be able to follow the history of satellite orbits, which is important to the problem of satellite origin.

The above experiments will be carried out with the landing station radio system and with the use of transmitting and receiving antennas. Range measurements should provide the basic information for these experiments.

Libration, a variation of orbital motion, is a significant characteristic of a celestial body's rotation. In the Solar System, Phobos is the only known body showing relatively high-amplitude libration during synchronous rotation and revolution; the libration amplitude is about 5°. The amplitude is high because the satellite's period of free libration of about 10 hours is close to its orbiting period of about 7.7 hours. Phobos's librations will be studied by measurements of the Sun's angular position with an optical detector on board the landing station.

A seismometer will measure seismic noise on Phobos caused by the Martian gravitational field, impacts with meteorites and the thermal expansion caused by passage from night to day.

Another group of landing station experiments aims to study the elemental composition of the surface layer, its structure and its physical and mechanical characteristics. The basic data on elemental composition will be acquired

from the orbiter by remote techniques. *In situ* measurements from the landing station are necessary mainly to facilitate interpretation of the remotely sensed data and to calibrate instruments. To this end, the landing station will carry a spectrometer for α -backscattering and x-ray fluorescence measurements, a penetrometer with temperature sensors, an accelerometer and a television camera with high spatial resolution.

The Phobos rover has the capability to hop over the surface and measure soil characteristics at various sites. Its shape is close to spherical, and a set of rods control its position on the surface. After it has hopped as far as 20 m, the position-control rods put it into the operational position for making a series of scientific measurements. The scientific instrumentation on this lander includes an accelerometer to measure accelerations due to impacts with the surface, an x-ray fluorescence spectrometer to study the chemical composition of the surface soil, a penetrometer to measure its physical and mechanical properties, and a magnetometer.

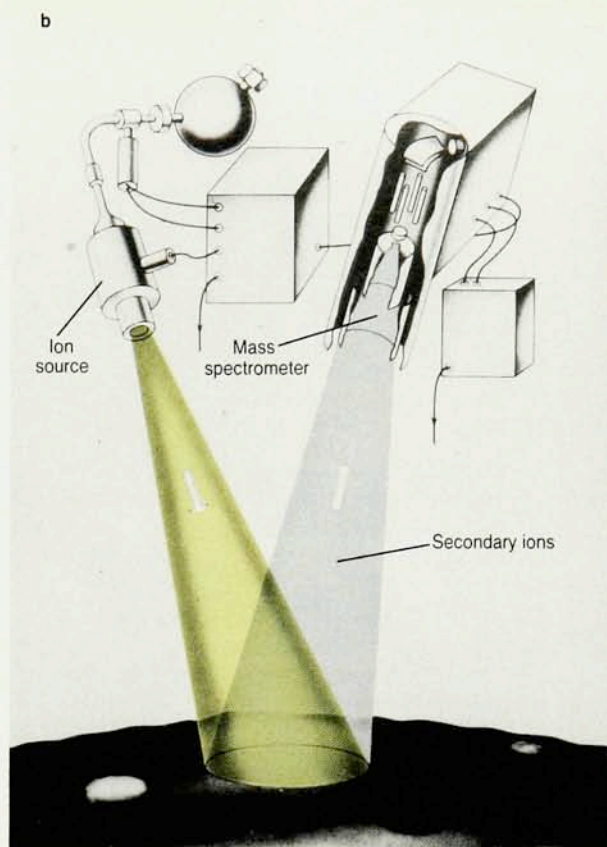
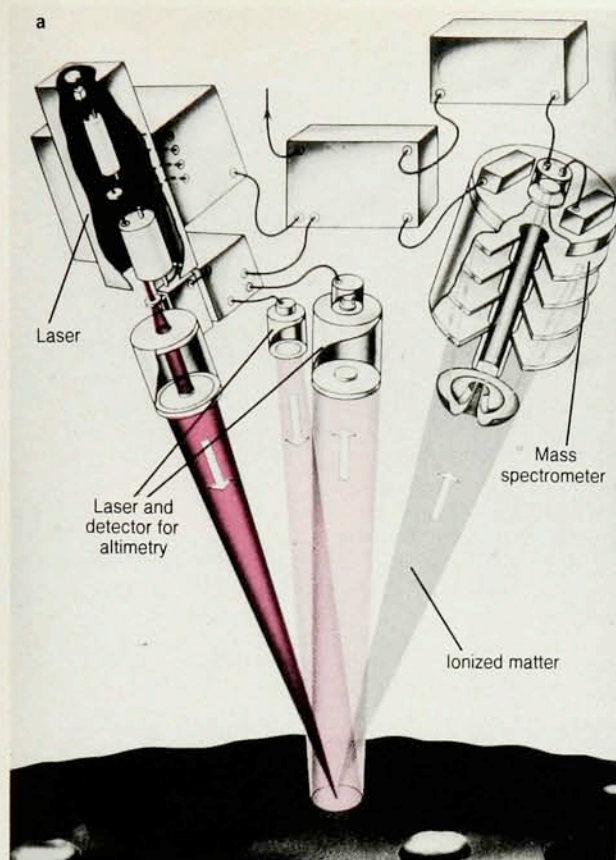
The USSR, France and the European Space Agency are discussing the cooperative project Vesta, aimed at studies of asteroids. This project, which might be realized as early as the mid-1990s, will include a flyby vehicle to encounter several asteroids and a station to land on the surface of one of them.

Mars

Space scientists will make a comprehensive study of the surface and climate of Mars in the 1990s after the Phobos mission. In 1992 the United States will launch its Mars Observer interplanetary spacecraft. We also plan to continue studies of Mars. At IKI we are discussing the scenario and capabilities of a mission in 1994. In its maximum-payload version, an automatic interplanetary complex would include a Mars orbiter, a rover, a balloon probe, surface probes and penetrators, and small weather stations on the Martian surface. One of the main objectives of this mission is to select the most interesting areas on the surface and to study them in detail. It is the orbiter, with its scientific payload for studying the surface and inner layers of the planet remotely, that will be primarily responsible for such experiments.

The areas thus selected on the Martian surface will be investigated by means of rovers. Now under development for the 1994 mission is a small rover capable of going several tens of kilometers and maybe more than 100 km, depending on surface conditions. (See figure 1.) The basic task of the rover will be to study soil characteristics at landing sites. We plan to develop a device for sampling soil at depths of several meters.

Another possibility for studying the surface of Mars by *in situ* methods is with a balloon that alternately drifts over and lands on the surface. The most reasonable configuration for such experiments seems to be a double balloon: a helium balloon on top and a radiation-heated hot air balloon on the bottom. The helium balloon will hold the hot air balloon envelope above the surface at night, thereby providing proper conditions for daytime warm-up and inflation. In daylight the hot air balloon and



Martian moon probes. A mission to Phobos is scheduled for launch in mid-1988. These schematic diagrams show laser sounding (a) and ion sounding (b) experiments to study the elemental composition of the moon. **Figure 6**

helium balloon together would provide enough lift to carry the payload. The system's lifetime in the Martian atmosphere would depend mainly on the rate of helium leakage from the balloon, and could be from two weeks to several months with a drift path of several thousand kilometers. Soviet, French and American groups are now developing versions of these balloons.

The periodic landings would provide a survey of the planet's soil and would help outline the boundaries of the cryolithic zone and determine the amount of water there. A camera would take panoramic images at landing sites with a resolution of about 1 mm.

The next stage of the study of Mars would probably be the return of Martian soil samples to Earth for detailed analysis. This mission, which might occur before 2000, should include an orbiter, a rover capable of sampling soil and subsurface layers within a 100–150-km radius, and a special device for delivering these samples to a return rocket.

The likelihood of implementing the mission to Mars in 1994 and the sample-return mission before 2000 depends mainly on the development of space technology. This program requires a launch vehicle with a powerful upper stage, an interplanetary complex to be assembled in Earth orbit, and a spacecraft designed to assure aerodynamic braking in the Martian atmosphere while shifting from the cruise trajectory to Mars orbit. There are many other problems as well—in particular, the problem of the Martian soil quarantine on Earth. From our viewpoint, however, it looks like these problems can be solved in the years ahead.

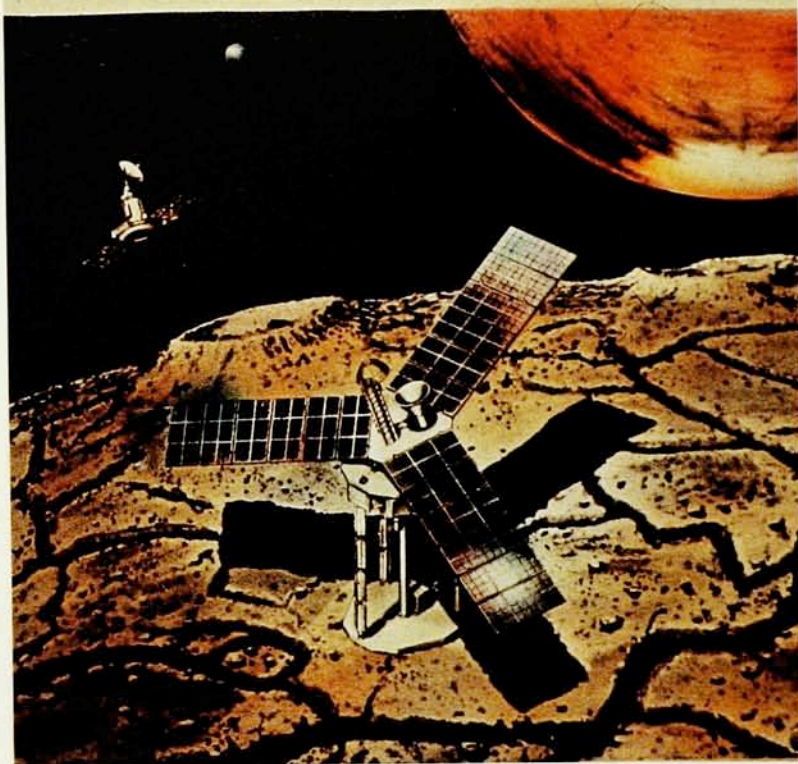
Studies of Mars made cooperatively by scientists from the USSR, the US and European countries before 2000 will give us a better understanding of that planet and provide conditions necessary for a joint manned Mars expedition, which could become a top-priority project as an imperative of nuclear disarmament policy.

Space plasma

Studies of plasma, electric fields, magnetic fields and wave processes in space have now been in progress for about 30 years. The findings have permitted concepts to be developed of the structures of the magnetospheres of the Earth and other planets; these concepts have been widely accepted since the beginning of the 1980s. However, several difficult-to-measure effects such as shock waves, magnetic field reconnection and turbulence call for a new generation of experiments. To understand cause-and-effect relationships between events in the complicated solar magnetospheric-ionospheric system it is necessary to probe different critical regions concurrently with the help of a wide network of artificial satellites and associated ground stations.

The Interball project would create a multiprobe system for investigating near-Earth space. This project, scheduled for 1990–91, would consist of a system of two Prognost-type satellites, each with its own subsatellite. The main objective of this project is to study the physical mechanisms responsible for transferring solar wind energy to the magnetosphere, the accumulation of this energy there and the subsequent dissipation of the energy in the auroral regions of the magnetosphere, ionosphere and

ДОЛГОЖИВУЩАЯ АВТОНОМНАЯ СТАНЦИЯ



Phobos landing station. The drawing shows the long-term autonomous station on the Martian moon. ("Long-term autonomous station" is written at the top in Russian.) The station is for time-consuming experiments; it is to have an active lifetime of about a year. Figure 7

atmosphere during magnetospheric substorms.

The Interball satellite system would make it possible to study two basic aspects of magnetospheric activity: cause-and-effect relationships and physical mechanisms of the events. One of the satellites—Tail Probe, with the S2-X subsatellite—will be launched into an orbit that passes through the magnetospheric tail, which is a reservoir of the energy of magnetospheric substorms. The other satellite—Auroral Probe, with the S2-A subsatellite—will be placed in an orbit that passes through the region above the auroral oval at heights of $5\text{--}15 \times 10^3$ km. This region is characterized by processes of auroral particle acceleration and the presence of electric currents that connect the emf in the magnetospheric tail with the conductive ionosphere.

Concurrently with these measurements, the Interball project would study the plasma and magnetic structures of distant regions in the magnetospheric tail using the instruments on board the Relict-2 astrophysical satellite, which is to be launched into a halo orbit around the Sun-Earth libration point L_2 (see figure 4). These measurements more than 1 million km from the planet will give us a better understanding of the process of particle acceleration, the dynamics of the magnetosphere as an integral plasma-magnetic system and the evolution of plasma structures in the tail during magnetic energy transformation.

Projects beyond the 1990-91 Interball mission have already been discussed. They will pursue further the ideas around which Interball and the International Sun-Earth

Explorer satellite system have been planned. To plot the full three-dimensional pattern of currents and plasma motions in the magnetosphere, measurements from two closely spaced satellites are no longer sufficient. Indeed, such measurements allow resolution of spatial and temporal variations in only one direction—along a line connecting the satellites. To retrieve a full three-dimensional pattern it is necessary to make measurements from a minimum of four vehicles. This helps explain the altruism of participants in international cooperative efforts who work together to develop configurations of many space probes. IKI plans to cooperate with the European Space Agency on the Cluster project, in which six spacecraft would make simultaneous measurements of plasma processes in Earth's magnetosphere.

A final word: Scientific merit is, of course, a very important element in decision-making in science programs. However, carefully assessing proposals and balancing topical projects inevitably leads to encounters with many other issues. One issue that is a source of hot debate is the unmanned versus the manned approach to space research. The optimal balance in such a competition is not always easily achieved. In most cases priority is given to political and institutional considerations. Needless to say, IKI shares James Van Allen's concern that costly manned missions will be pursued at the expense of projects that would better advance space science. In the long run, however, we have to beware of an even more dangerous competition—that between military and civilian uses of space. ■