

**FOREIGN APPLIED SCIENCES ASSESSMENT CENTER**

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**FASAC**

**TECHNICAL ASSESSMENT REPORT  
FASAC-TAR-3060**

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**SOVIET SPACE SCIENCE RESEARCH**

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**31 January 1986**

***SAIC* Science Applications International Corporation**

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# FOREIGN APPLIED SCIENCES ASSESSMENT CENTER

## PURPOSE

The Foreign Applied Sciences Assessment Center (FASAC) is operated for the Federal Government by Science Applications International Corporation (SAIC) to improve U.S. knowledge of applied science and to increase awareness of new foreign technologies with military, economic or political importance. Such knowledge can reduce technological surprise, can support estimates of the consequences of technology transfer, and can provide a background for U.S. research and development decisions.

The Center directs leading U.S. scientists in the preparation of technical assessment reports and provides continuity as a national forum for periodic reviews of foreign science.

## REPORTS

Although FASAC examines world applied science, emphasis is placed on research in the Soviet Union. The Center reports on what the Soviets call exploratory research (akin to Department of Defense 6.1 and 6.2 research), which seeks to translate developments in fundamental research into new technology. The Center does not generally report on technology already being incorporated in engineering applications.

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Each panel assesses the status of foreign applied science in a selected area and its potential impacts. Panel members are selected by the following criteria: leading authority in the field; recent "hands-on" experience; knowledge of foreign research; and knowledge of the direction of U.S. research programs.

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The Director, Science Coordinator, and Senior Scientist help select the topics to be assessed, select the Panel Chairmen, guide and assist the preparation of panel reports, and with the Integration Committee combine panel reports into more comprehensive, multi-disciplinary assessments of foreign applied science.

The Science Coordinator helps to identify and enlist the help of the best qualified experts, communicates with the U.S. academic and government research community, and participates in the preparation of reports.

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**FASAC Technical Assessment Report (TAR) 3060**

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## ABSTRACT

This report is the work of a panel of eight US scientists who surveyed and assessed Soviet research in the space sciences. All of the panelists were very familiar with Soviet research through their knowledge of the published scientific literature and personal contacts with Soviet and other foreign colleagues. In addition, all of the panelists reviewed considerable additional open literature--scientific and popular, including news releases.

The specific disciplines of Soviet space science research examined in detail for the report were:

- solar-terrestrial research,
- lunar and planetary research,
- space astronomy and astrophysics, and,
- life sciences.

The Soviet Union has in the past carried out an ambitious program in lunar exploration and, more recently, in studies of the inner planets, Mars and especially Venus. The Soviets have provided scientific data about the latter planet which has been crucial for studies of the planet's evolution. Future programs envision an encounter with Halley's Comet, in March 1986, and missions to Mars and asteroids.

The Soviet programs in the life sciences and solar-terrestrial research have been long-lasting and systematically pursued. Much of the ground-based and space-based research in these two disciplines appears to be motivated by the requirement to establish long-term human habitation in near-Earth space.

The Soviet contributions to new discoveries and understanding in observational space astronomy and astrophysics have been few. This is in significant contrast to the very excellent theoretical work contributed by Soviet scientists in this discipline.



# SOVIET SPACE SCIENCE RESEARCH

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## FOREWORD

This technical assessment report, Soviet Space Science Research, is one of a series developed under the auspices of the Foreign Applied Sciences Assessment Center (FASAC), which is operated for the Federal government by Science Applications International Corporation.

This report focuses on Soviet space science research in the biological and life sciences, solar-terrestrial relations, lunar and planetary exploration, and astronomy and astrophysics. The report was prepared by a panel of internationally recognized researchers active in space science investigations:

- Dr. Louis J. Lanzerotti (Panel Chairman), AT&T Bell Laboratories
- Dr. Richard C. Henry, The Johns Hopkins University
- Dr. Harold P. Klein, University of Santa Clara
- Dr. Harold Masursky, US Geological Survey
- Dr. George A. Paulikas, The Aerospace Corporation
- Dr. Frederick L. Scarf, TRW, Inc.
- Dr. Gerald A. Soffen, NASA Goddard Space Flight Center
- Dr. Yervant Terzian, Cornell University

The primary data base has been the published Soviet scientific literature. However, all of these experts have also been exposed to Soviet space science research and researchers at various international conferences, and several have been personally involved in past US/Soviet cooperative space activities. They are thus uniquely qualified to assess the technical strengths and weaknesses of the Soviet space science establishment.

Because of the importance of timeliness in this research area, the individual panel members expedited their work. The major efforts on the technical assessments in this report were made during the interval from January to July 1985, with the report essentially completed by the end of 1985.



## EXECUTIVE SUMMARY

This technical assessment of Soviet space science research in the four discipline areas of biological and life sciences, solar-terrestrial relations, planetary exploration, and astronomy and astrophysics was prepared by a panel of internationally-recognized scientists who have a deep familiarity with the international published literature in the space sciences as well as acquaintances with the key space science individuals in the West and in the Soviet Union. The report does not pretend to address the multitude of political considerations involved in a scientific area such as this, an area that has profound political ramifications. Rather, the authors have used their individual scientific expertise to arrive at the assessments presented. These scientific assessments must be embedded in a broader framework of other relevant considerations when the total picture of Soviet space research in comparison to that in the West is made.

A guiding motive for the Soviet research in the biological and life sciences appears to be the desire to understand the constraints and the possibilities for the long-term human occupation of space. A consistent experimental space program has been pursued for two decades in this discipline, with dedicated life science missions flown at two- to three-year spacings.

In solar-terrestrial research, the Soviet space science effort has built upon a long history of ground-based research related to studies of the upper atmosphere and aurora and the prediction of geomagnetic activity. A considerable amount of the Soviet research in solar-terrestrial relations is concerned with predictions of the space environment and appears to be motivated to a significant extent by the desire for long-term habitation in space. Again, Soviet solar-terrestrial missions are spaced on approximately two- to three-year intervals and have become increasingly sophisticated in their studies of the Earth and interplanetary plasma environment. This is in considerable contrast to the situation in the United States, where it is possible that this area of research will no longer be an important one in US space activities.

In planetary exploration, the Soviet Union has concentrated on the inner planets, Venus and Mars, and has developed a very sophisticated and continuing program for the exploration of the details for the hostile atmosphere and surface conditions of Venus. Future sophisticated missions to Mars have been announced. Soviet research has not yet

addressed the outer planets. Further, Soviet planetary research does not encompass, to any significant extent, experimental activities related to the origins of life or the search for extraterrestrial intelligence (although in this latter area there is much written theoretical work).

The Soviet Union has contributed relatively little compared to Western nations in experimental space astronomy and astrophysics. This is in spite of Soviet eminence in theoretical work in these areas and their published claims to the contrary. While there have been a number of dedicated telescopes in space, the science returns as revealed in the literature and in international meetings have been small.

Scientific payloads on Soviet spacecraft have recently included significant contributions from Western nations, particularly France, Sweden, and the Federal Republic of Germany. Western state-of-the-art instruments have been flown on solar-terrestrial, planetary, and astronomy missions.

In summary, Soviet activities in space research have made significant contributions to selected areas of space science. A strong and continuing effort continues in planetary exploration. Strong efforts continue in the biological and life sciences and in solar-terrestrial research as well. In these latter two areas, much of the research appears to be motivated by understanding the constraints on long-term human habitation in space.

## CHAPTER I ASSESSMENTS

### A. INTRODUCTION

Research in space science, unlike much of the research in other areas of the natural and physical sciences, is quite often a highly visible aspect of a nation's technological prowess. Research activities in space science readily convey to the world population the level of sophistication of technological achievement that a nation has attained. Space science research, therefore, is often inseparable in the minds of citizens and policy-makers from national technological goals and objectives, as well as national striving for international prestige and commercial and military power. These generalities, while only that, appear nevertheless to be valid for all the nations in the world who are presently engaged in space science research. Because of the visibility which access to space provides the nations that attain it, many analyses of the political milieu in which space flight activities are embedded have been published since the dawn of the space age, particularly those related to manned space flights (e.g., books by such authors as Frutkin, 1965; Logsdon, 1970; Newell, 1980; Oberg, 1981; McDougall, 1985; OTA Technical Memorandum, 1985).

The analyses in this volume, written by working scientists knowledgeable about US and international space science research, approach the assessment of national space science activities from a considerably different vantage point than most other works. That is, using their personal knowledge and expertise gained from active space science research, including knowledge of the literature and acquaintanceship with many of the key international scientists, the contributors have made assessments on the level of activity and quality of space science research in the Soviet Union today. The scientific assessments that are made here do not take into account political and other considerations that might motivate national space science research objectives, inasmuch as such considerations are outside the expertise of the individuals contributing to this volume and have been addressed by other writers. The assessments also do not evaluate the level of success of Western experiments flown on Soviet spacecraft, a practice that is of growing importance in the Soviet scientific space program.

## **B. EVALUATION OF SOVIET SPACE SCIENCE**

Assessments have been made of past and present Soviet space science research in the areas of the biological and life sciences, solar-terrestrial relationships, planetary explorations, and astronomy and astrophysics. Vast differences were found in the emphasis and in the quality of the published Soviet work in these key areas of space science.

There have been long and continuing Soviet space-based research efforts in solar-terrestrial relations and in the biological and life sciences. Research activities in these fields have existed since the time of the first Sputnik and continue to be pursued extensively today. Actually, as in the United States and in other technologically-oriented nations, much Soviet ground-based research in solar-terrestrial studies preceded Sputnik 1. This ground-based research continues, but is often not integrated well with the space-based measurements. Soviet research in planetary exploration, although vigorously pursued with varying degrees of success at various times in the past, has now arrived at the point where the research excellence in the exploration of Venus and the research thrusts directed towards comets lead those of the United States. In a significant contrast, little has been published of Soviet experimental research results in space astronomy and astrophysics, and very few major observational discoveries in these fields have resulted from Soviet efforts. The theoretical contributions of Soviet scientists in astronomy and astrophysics, however, have been of first rank.

Long-term habitation of humans in near-Earth space appears to be the principal theme underlying Soviet research in the biological and life sciences and considerable amounts of the research in solar-terrestrial relations. As the individual chapters on these two topics point out, the emphasis on the long-term existence of humans in space encompasses a wide spectrum of research objectives. For example, in the biological realm, considerable life science research is being conducted on the effects of radiation on a wide variety of living organisms, ranging from plants to humans. In the context of solar-terrestrial research, the significant emphasis in the published literature on the predictability of solar activity, encompassing not just space flight experiments but also the construction of new, large ground-based solar radio telescopes, is consistent with the objective to understand the limiting factors on the survivability of humans in the space environment. This survivability objective is also evident in considerable amounts of

the Soviet published work devoted to the understanding of the dynamics of trapped radiation in the Earth's magnetosphere and of propagation of charged particles in the interplanetary medium from the sun to Earth orbit.

The Soviet unmanned lunar and planetary program has concentrated on the Moon, the two inner planets, Venus and Mars, and, more recently, on comets. The Soviet research around and in the inhospitable environment of Venus has been outstanding. Soviet measurements have provided key data for understanding the evolution of the planet. The instrumentation designed for operation in the Venusian environment has performed exceptionally well. Soviet unmanned rovers have roamed the lunar surface; samples have been returned to Earth. In the United States, planetary exploration encompasses not only the in situ and remote sensing studies of all planets (except Pluto) in the solar system, but also the scientific search for planets around other stars, theoretical considerations of the details of the formation of planetary systems, and the intellectual challenges associated with exobiology and the origins of life. With the exception of some presently developing experimental activities and considerable theoretical work related to the search for extraterrestrial intelligence, the Soviet space research program does not appear to have incorporated to a significant extent studies of the origins of life. The Soviet planetary program provides little, if any, evidence of its being conducted for purposes related to the survivability of humans in space or of the origins of life.

Contributions of Eastern Bloc scientists to the principal problems in contemporary observational astrophysics have been few. The possible major exception is the work related to gamma ray bursts. It is considered strange that while the detector technology required for x-ray astronomy in its early days did not require much sophistication beyond that used for gamma ray studies, Soviet scientists did not participate to any significant extent in pushing forward the frontiers of astrophysics in the x-ray regime. Soviet scientists, however, have been very active in studies of auroral x-rays in their solar-terrestrial program. In contrast, exceptionally intense and excellent Soviet theoretical astrophysics research relating to important current problems is continuing. This includes research on the nature of supernova, pulsars, galaxies, and quasars and their relevance for understanding the origins of the universe.

Soviet space science research appears to be consciously pursued as a scientific enterprise, an activity which proceeds in a systematic fashion, building upon current understanding of a phenomenon or a process to probe more deeply with the next mission into the fundamental underlying physical, chemical, and biological processes. This method of approach is an important common element that threads through the research efforts in the Soviet biological and life sciences, solar-terrestrial research, and the focused planetary program. This is the manner in which laboratory-based science basically operates today: experiments that discover and understand some new aspect of nature are followed up using new theoretical ideas and/or instrumentation techniques in order to search for deeper physical understanding and the interrelationships to other known phenomena. The Soviet space science program clearly seems to provide periodic flight opportunities, spaced on two- to three-year (or even shorter) cycles, in each of the main discipline areas other than astrophysics: life sciences, solar-terrestrial research, and the focused planetary program. The Soviet literature clearly illustrates that current missions are built upon the previous missions and generally fly the next generation of instrumentation in order to answer more detailed scientific questions.

An example of this cited in the Life Sciences Research chapter (Chapter V) is the implementation of centrifuges on a succession of Soviet life science spacecraft. Beginning with a small and rather unsophisticated instrument, the Soviet program has built up to much larger and more sophisticated devices required for answering more detailed biological questions. In contrast, no dedicated space biological missions have been flown by the United States for over two decades.

A similar Soviet evolution is evident in the solar-terrestrial research area where rather simple instrumentation, initially provided, for the most part, by a group at Moscow State University (Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova) and oriented toward cosmic ray research, has been upgraded and augmented considerably by sophisticated plasma instrumentation in order to provide detailed diagnostics of the space plasma environment. The present plans of the Soviet Union appear clearly to be a continuation, on approximately two-year cycles, of an intensive investigation of the solar system plasma environment, with missions targeted to specific science objectives. This is in contrast to the US plans. While there have been several sequential US programs in solar-terrestrial research at an Explorer-class satellite level, it is not clear at present whether the nation will to any extent continue its efforts in this field of research.

The apparently systematic Soviet approach to these elements of space science contrasts sharply with the more specific mission-oriented approach pursued in the United States and in Europe, where the individual missions are the essence of the program. In the United States, one mission may be followed systematically by another, such as the Galileo mission following upon the discoveries of Pioneer and Voyager at Jupiter. However, in most instances, a single mission is viewed as the ultimate for the particular science in question. An important case in point is the Viking mission to Mars, where no further Martian exploration by the United States is expected to occur for as many as 15 years following the landing of Viking on the surface. Both the United States and the Soviet Union have deferred further lunar exploration, with the Soviet Union concentrating on its systematic exploration of the planet Venus, while the United States has been largely emphasizing the outer planets.

The motivations behind these systematic Soviet space science explorations are uncertain, both from an understanding of the literature and from discussions with Soviet colleagues. This systematic pursuit appears to be primarily based upon scientific imperative where, as noted above, discoveries and understandings are expected to be followed up by further, more detailed, research. It is, however, likely that some of this continued systematic work is a result of the intrinsic nature of the Soviet science system, where considerable built-in inertia exists. If a factory can make one spacecraft, it can easily continue to make several. However, if the inertia factor has any role to play in the systematics of Soviet space research, the assessment is that it has operated largely to the benefit of Soviet space science: it has allowed for more systematic planning of both space and ground-based experimentation in order to achieve scientific objectives.

### **C. COMMUNICATIONS AMONG THE SPACE SCIENCE COMMUNITIES**

The communication of the results of Soviet space science research in the Soviet and (occasionally) Western literature is often very delayed compared to Western publications. As such, Soviet results are not cited as frequently in the Western literature as are Western results cited in Soviet papers. Whether or not such an asymmetry in citations is solely due to publication delays or is also partially a reflection on the quality of substantial published work is not clear for all fields. However, as noted earlier, in the case of astrophysics, it reflects the quality of the Soviet experimental results to date. This aspect of the "interactions" of Soviet scientists with their international colleagues

has been recently discussed by Kneen (1985), who synthesizes considerable sociological research on scientific communications and concludes that, on every level, the interactions of Soviet scientists with their international peer group are severely limited compared to those available in the Western world. Medvedev (1978) historically traces the long-standing Soviet obsession with "secrecy" in the publication of preliminary as well as final scientific results, an analysis which is quite applicable to space science.

The long delays in publication, particularly in their own Soviet journals, produces an interesting phenomenon often encountered by Western scientists attending international meetings. The latest Soviet space science results are generally presented orally at these meetings, often by the same individuals at meeting after meeting. In these forums, the most recent Soviet results, data processing and analysis techniques, and theoretical thinking are expounded. However, often, many of the projects and results discussed never seem to appear in the published Soviet literature. In addition, results such as Soviet planetary photographs are frequently provided to selected Western scientists for examination and retention and, it would appear, for further dissemination in the Western scientific world. Such a method of dissemination of results favors the selected Western scientists; and those Western scientists and graduate students who are not the favored recipients of such materials are perforce hindered in the pursuit of their research if it requires the input of such new Soviet results.

Many of the most important and exciting Soviet space science results appear in Western publications, often co-authored with Western scientists. Particularly good examples are the Soviet contributions to the studies of Venus as contained in the volume, Venus (Hunten et al., 1983)--edited by three Americans (Hunten, Colin, and Donahue) and one Soviet (Moroz). The exposition of Soviet results from Venus was significantly facilitated by the scientific cooperation between the two nations, both of whom had at the time on-going vigorous missions to study the planet.

It should be noted that some aspects of the Soviet space science communication system are rapidly evolving at present. Planetary (Venus) encounters have recently been covered by press conferences which are chronicled in Pravda and by the Tass news service. Americans have attended encounter activities and press conferences. There is some indication that the Soviets will adopt "preliminary science reports" for some missions, similar to Western "30-day reports."

#### **D. SUMMARY**

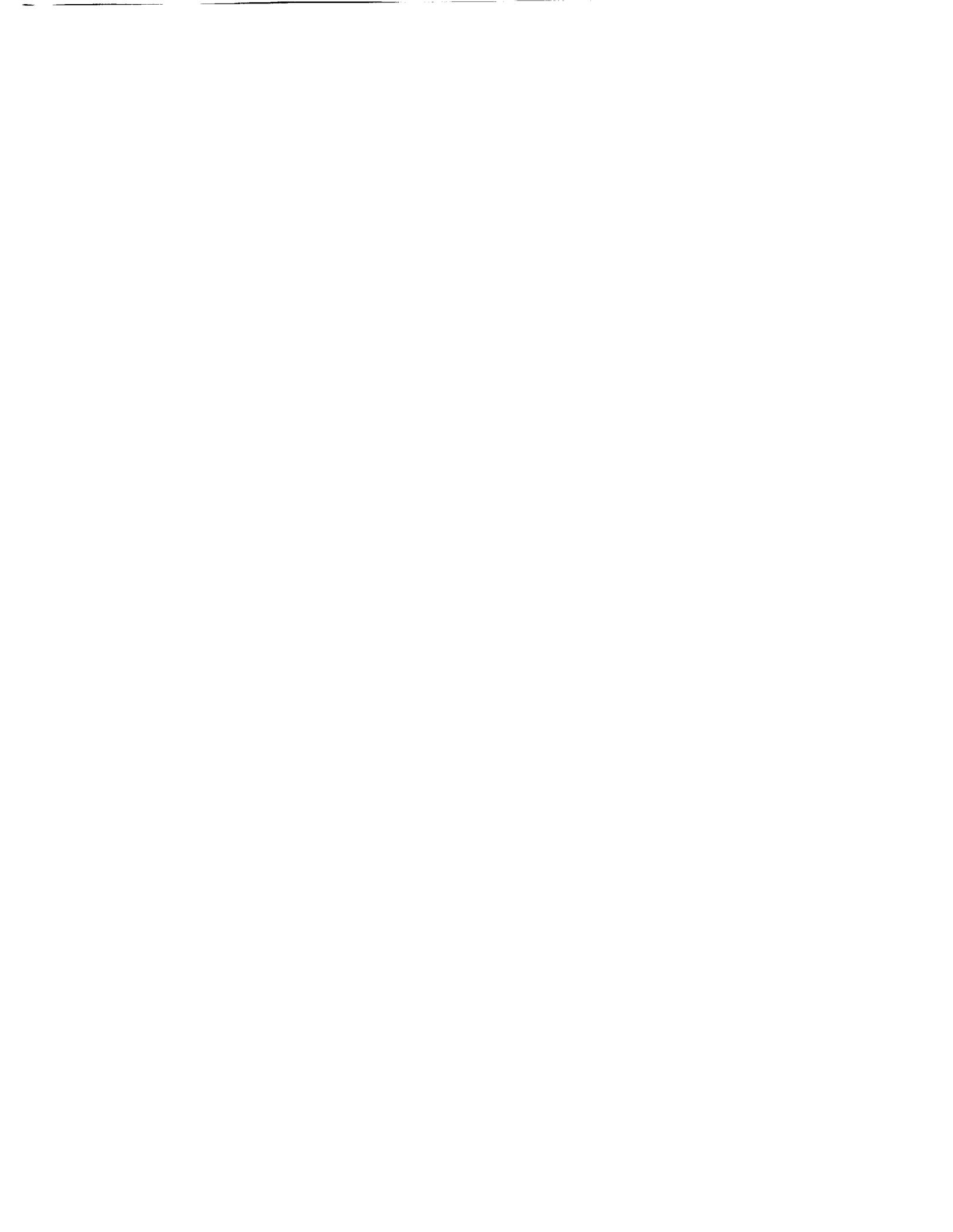
The Soviet Union has a very high space science visibility in the world, probably second only to the United States. Much of this visibility comes from the recent excellence of the lunar and planetary program, which has concentrated on studies of the Moon, Venus, and Mars. The Soviet Union has performed innovative measurements on and around both the Moon and Venus. The Soviet manned space program also provides high visibility. The systematic Soviet research in space biology and life sciences and in solar-terrestrial studies seems to be motivated to a very significant extent by the requirement to understand the near-Earth space environment for purposes of human habitation. The Soviet space missions in each of the areas of biology and life sciences, solar-terrestrial research, and planetary exploration appear to be pursued systematically, with regular missions, each of which build upon recent results. The Soviet contributions to observational space astronomy and astrophysics are very few. There is strong evidence that the lack of scientific computing power in the various participating research institutions significantly hinders the Soviet analyses and synthesis of space-derived data. Finally, in recent years, the Soviet Union has increasingly promoted and offered opportunities on its scientific spacecraft for flights of state-of-the-art experiments by Western scientists. Nations which have participated to a significant extent include France, Sweden, and the Federal Republic of Germany.



## CHAPTER I: ASSESSMENTS

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## CHAPTER II SOLAR-TERRESTRIAL PHYSICS

### A. OVERVIEW

Solar-terrestrial physics (STP) encompasses diverse fields of research, joined together by the central objective of studying the flow of energy (in the form of particulate and electromagnetic radiation) from the sun to the earth and the effects of that energy flow on the space and atmospheric environment in the immediate vicinity of the earth. Solar-terrestrial physics thus includes elements of:

- solar physics,
- the physics of the interplanetary medium including solar cosmic rays,
- magnetospheric and radiation belt physics,
- ionospheric physics, and
- the physics of the upper ( $h \gtrsim 100$  km) atmosphere.

Needless to say, the fields of study enumerated above do not form distinct, sharply bounded entities. The thrust of much of the modern research in the field of solar-terrestrial physics deals with coupling mechanisms, i.e., the coupling of the interplanetary medium to the magnetosphere, magnetosphere-ionosphere-upper atmosphere coupling, etc.; but for simplicity in the discussions below, we have arbitrarily segregated Soviet research in STP into the major divisions enumerated above.

Our analysis of Soviet work in STP has necessarily been carried out in the conceptual framework derived from the research standards applied to US work in this field. As will become evident, the United States has been the leader and principal contributor to advances in solar-terrestrial physics and, with a few important exceptions, has dominated the field. In many areas of STP research, there is a pervasive US influence, in the sense that citations of US work in Soviet papers outnumber the citations of Soviet work. An important caveat is in order. The body of scientific work reviewed for the present purposes was submitted for publication principally during the 1976-1982 interval. Given the monumental publication delays apparently endemic to Soviet space

science, the present analysis of Soviet work is perhaps representative of their state of knowledge in the mid- to late-1970's. While the United States presently enjoys a substantial lead in virtually all areas of solar-terrestrial physics, the relative paucity of US space missions with solar-terrestrial objectives in recent years--as contrasted with an apparently steady launch rate of Soviet spacecraft designed, at least in part, to carry out space science research--may, in time, result in the slow erosion of the US lead in certain sub-fields of solar-terrestrial physics.

Analysis of Soviet research in solar-terrestrial physics, as in other fields of endeavor, is hampered by several factors. The Soviet (i.e., Russian) style of writing tends toward the terse, with little if any development of the technical ideas within the body of a paper. Conclusions are drawn without any apparent justification, and theoretical formulations are injected abruptly. (However, papers by Soviet authors in the refereed Western literature are highly readable and comparable in quality of presentation to Western work; see Zaytsev, 1984.) One is overwhelmed by apparently pedestrian work which makes only very small incremental contributions to the body of knowledge. There is much repetition of US work in the field--but there are also genuine advances and improvements over US efforts and exploration of scientific areas which have not received the attention of US workers. One gets the overall impression of a steady, plodding effort, moving ever-forward at a glacial pace. It is also quite clear that such sampling of the Soviet literature as we have done, concentrating principally on the journals Cosmic Research (Kosmicheskiye issledovaniya) and Geomagnetism and Aeronomy (Geomagnetizm i aeronomiya), is not entirely representative of work in the field. We have not had an opportunity to review the many Soviet conference proceedings and other citations which appeared in the papers which we examined, as they were not available through the open literature sources.

Soviet insight into important issues of solar-terrestrial physics appears to be on par with US thinking of about 10 years ago, but with the important qualification that most of the ideas current in the United States in 1975 still have not been converted into approved programs. Soviet instrumentation aboard spacecraft seems relatively primitive, and data analysis/data presentation appears to be hampered by lack of access to computational facilities. However, the increasing cooperation with the West in space research (Sweden--see Yau, 1985--France) appears to provide a means of injecting current Western technology into Soviet solar-terrestrial physics efforts, so that the magnitude of the US lead in space instrumentation is likely to decrease in the future.

Any program of research in space science necessarily depends on spaceflight opportunities. Appendix A of this report contains a list of spacecraft, together with their orbital parameters, which were cited in the Soviet literature we surveyed. (The orbital parameters and other commentary in Appendix A were gathered from the open literature available in the United States.) Not listed in Appendix A are the families of interplanetary and lunar spacecraft (Mars, Venera, Luna) which provided the rides for some of the experiments that made measurements on the properties of the interplanetary medium and cosmic rays. It seems clear that the Soviet investment in launches devoted to near-earth space science significantly exceeds that of the United States, although the visible scientific output per mission seems rather low. There is also a seeming rigidity to the program--the same orbital parameters are flown again and again, even taking into account the fact that a substantial fraction of the Soviet space science effort is carried out by experiments flown as secondary payloads on military spacecraft whose orbital parameters are driven by other considerations. If the experiences of the past can be used to predict the future, it would seem that the orbital configurations employed by the Prognoz and Interkosmos families, for example, will continue to be utilized with all of the limitations--and opportunities--that this implies.

In the sections below, we attempt to assess the current status and possible future directions in Soviet research on the physics of the sun (as it is connected with solar-terrestrial physics), the interplanetary medium, cosmic rays, the magnetosphere, the ionosphere, and the upper atmosphere.

## **B. SOLAR PHYSICS**

### **I. Introduction**

Our detailed review of Soviet work in solar physics has been limited to those aspects of the field that bear on or are directly connected with solar-terrestrial physics. Therefore, included in this review are the sub-fields of:

- solar activity research,
- research on solar flares,

- solar activity forecasting, and
- the coupling of solar particulate flows to the interplanetary medium.

Not included in our review are such topics in solar physics as radiation transport, solar magnetohydrodynamics research (not specifically bearing on solar activity), and such topics as the structure of solar granules and supergranules and "solar seismology."

## 2. State of Research

The general impression we obtained from our review is that the thrust of Soviet research in the solar-terrestrial aspects of solar physics is dominated by an interest in forecasting solar activity and its effects, ranging from short lead-time forecasting of individual solar events to forecasting the evolution of the postulated 80-year cycle of solar activity. The work on forecasting the temporal and spectral characteristics of solar cosmic rays based on various indicators has a particularly applied flavor (Bezruchenkova et al., 1978; Val'chuk et al., 1981) and is strongly reminiscent of research in this field carried out in the United States in the 1970's at the NOAA Space Environment Laboratories and by Air Force Geophysics Laboratory (AFGL) researchers. Prominent Soviet researchers in this field are N. K. Pereyaslova, S. T. Akin'yan, and I. M. Chertok (Akin'yan et al., 1977a, b, c; 1978; Pereyaslova and Mikirova, 1980). The principal work in this field appears to be carried out at the Institute for Terrestrial Magnetism (Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln) and the Institute of Applied Geophysics (Institut prikladnoy geofiziki). Soviet research on the forecasting of the properties of solar proton events appears to be broader than US efforts in this field at this time. There are hints that the results of this (Soviet) research have been applied in an operational way, and there are suggestions that some techniques of monitoring solar radio emissions may result in better warning and alert performance, but we have not found any discussion of the software that would be required to couple empirical forecasting techniques with models of solar proton propagation through the interplanetary medium in order to arrive at truly useful solar proton forecasting tools. All of the scientific elements required to assemble such a forecasting tool seem to exist in the Soviet Union.

The work by Mustel' and his colleagues (Markov and Mustel', 1983; Chertoprud et al., 1979) on the possible connection between solar activity and effects induced by such activity in the troposphere continues to appear in the Soviet literature. The late John

Wilcox pursued this line of research in the United States, in some instances collaborating with Mustel' in this work. This field of investigation has been (in the United States) somewhat controversial and is receiving less attention now than it did some years ago.

A considerable amount of work on the analysis of individual solar flares/solar proton events appears in the Soviet literature (Morozova et al., 1977). The quantity of publications is substantial and would seem to be larger than US efforts of analysis covering these same events. The work, in some cases, draws on US data sources (OSO-7, Solrad, Skylab), and cites US results and references extensively. Such Soviet instrumentation as is described does not approximate the level of sophistication reached by US experimenters on such missions as Solar Max or P78-1. However, the experimental and analytic techniques employed are solid, conservative, and adequate for the task. Soviet experimental work in solar physics from space appears to be conducted from a variety of platforms: interplanetary spacecraft, spacecraft of the Prognoz series as well as aboard the Intercosmos missions. There is one description of a study of a spacecraft resembling the US Solar Probe concept. With this single exception, there are no other references to an expansion (or dedication) of space missions for exclusively solar physics research.

Finally, we must mention a class of work apparently in progress in the Soviet Union which has no counterpart that we know of in the United States--studies of the possible connection between solar activity and biological systems. A sample title will suffice to illustrate: "Research on the Connection of Solar Activity and the Severity of the Effects of Transport Accidents in Moscow" (Problemy kosmicheskoy biologii, 43, 1982, 59-63). We recall similar work, reported in anecdotal fashion (in The National Enquirer!) in the late 1970's, allegedly relating the incidence of heart attacks to the solar activity cycle. Without access to the database on which the analyses are performed, no statement regarding the credibility of this work is possible.

### **3. Outlook**

The strong trend of focusing solar physics research on forecasting techniques has been a hallmark of Soviet solar physics for more than 20 years. This persistence and the magnitude of this effort are presumably connected to the continued need for warning and

alert services for their manned spaceflight program, which utilizes high-inclination orbits, as well as for the need to forecast the quality of high frequency (HF) communication links. HF communications are utilized extensively in the Soviet Union.

Development of forecasting techniques involves a mixture of science and empiricism and a replacement of empirical approaches as quantitative understanding of the complex solar phenomena involved is developed. It is clear that some progress has been made in the past 20 years by Soviet (and US) researchers. Soviet contributions have received international recognition, but no potentially spectacular advance that will change the course of solar event forecasting is apparent at this time. We should note, however, that the Soviet effort in this field appears to be substantially larger than US work, of comparable quality to US work, and tenacity and persistence may pay off.

## **C. THE INTERPLANETARY MEDIUM**

### **1. Introduction**

In this section we review the Soviet work on the physics of the interplanetary medium. In descending order of emphasis, Soviet work in this field falls into the categories of:

- solar cosmic ray propagation,
- studies of the solar wind plasmas (general),
- geomagnetic effects of the properties of the interplanetary medium,
- interactions of the solar wind with planets and comets,
- plasma waves and turbulence in the solar wind,
- interplanetary shocks and discontinuities,
- energetic storm particles, and
- flare and stream dynamics.

Soviet research in this sub-field of solar-terrestrial physics is based on an extensive database obtained from their interplanetary spacecraft (Venera, Mars), the Prognoz series, as well as from other platforms (Raduga), and complemented by an extensive theoretical effort--not necessarily connected to the experimental work.

## 2. State of Research

The properties of solar cosmic rays, the physics of their propagation through the interplanetary medium, and the interaction of solar cosmic rays with the earth's magnetosphere form a major focus of Soviet research. The Soviet philosophy of "energetic particle detectors everywhere" has paid off in a massive database on high energy electrons and protons in the interplanetary medium and an outpouring of papers (Vernov et al., 1979, 1983; Volodichev et al., 1979; Klimenko, 1979; Blokh et al., 1979; Kuzhevskiy et al., 1979). The magnitude of the research effort exceeds that of the United States; unlike other instances we have seen, in this area Soviet work is relatively independent of US efforts, and the relative lack of citations of US work is one indication of this independence. The publications we have reviewed resemble nothing so much as a catalog, as event after solar event is analyzed using standard techniques. We also found several papers analyzing the biological effects of solar cosmic ray events and the assessment of the probabilities of the accumulation of various levels of radiation dosages by cosmonauts, suggesting that the massive research investment in solar cosmic ray research is driven at least in part by practical considerations (Kolomenskiy and Petrov, 1979). The driving force of Vernov (now deceased) is also in evidence; it remains to be seen whether his death and the retirement of some of the early pioneers of Soviet space research (ex-cosmic ray physicists) will change the course of work in this field.

Once one leaves the work on energetic solar cosmic rays, Soviet work seems less impressive. To be sure, we see good solid work in several aspects of solar wind physics (Pisarenko et al., 1983), a general improvement of instrumentation techniques (approaching US standards of 10 years ago), the influx of instrumentation of Western European origin onto the Prognoz series, and evidence of the development of sufficient data analysis capacity so that distribution function display of data is beginning to appear in association with the later Prognoz missions. There still remains a dependence on US data sources and an apparent lack of connection between analysis of data and theoretical work--the theoretical work on plasma waves and turbulence in the interplanetary medium, for example, is not connected to any experimental data, except for citations of US work. There are also papers which probably would not pass a US referee--discussions of the effects of the sector structure of the solar wind affecting the earth's rotation rate are based on extremely skimpy evidence.

### **3. Outlook**

Continued progress in research in interplanetary physics is based on access of instrumentation to the region of space well beyond the earth's magnetosphere. As mentioned earlier, Soviet scientists have used a number of spacecraft families to gather data on the properties of the interplanetary medium. Interplanetary missions, one of the families which have carried the instrumentation of interest, are driven by the considerations of planetary exploration; and instrumentation to study the properties of the interplanetary medium itself would typically be second in priority, albeit not very demanding of spacecraft resources. One can thus reasonably expect that future Soviet interplanetary missions will contribute data on the interplanetary medium. On the other hand, the Prognoz series seems to be specifically configured for studies of the near-earth interplanetary medium and appears to have considerable momentum, with one launch occurring every other year, the most recent in April 1985. Such trends as we see point to a continuing evolution and upgrading of the instrumentation on these spacecraft. In view of the paucity of US missions in this area of solar-terrestrial physics, it is not unreasonable to expect that Soviet work may come to dominate this field of research in the future.

## **D. MAGNETOSPHERIC PHYSICS**

### **1. Introduction**

Research on the physics of the magnetosphere appears to be the major area (in terms of quantity of publications) of interest in Soviet solar-terrestrial physics. This is the "classic" space science, which had its origins in the discovery of the Van Allen belts in 1958. Soviet researchers continue to pursue a broadly based research program in this field, making use of the numerous spaceflight opportunities available to them.

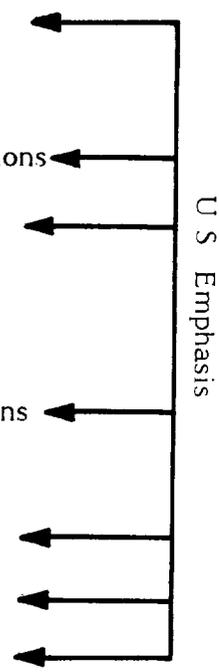
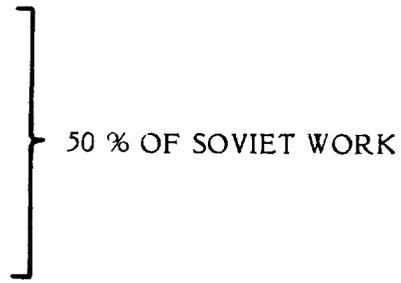
### **2. State of Research**

Approximately half of the effort in the general area of magnetospheric physics is devoted to research on radiation belt physics (Senchuro and Shavrin, 1978; Panasyuk, 1980, 1982) and the precipitation of energetic particles from the magnetosphere into the atmosphere (Kuznetsov and Stolpovskiy, 1978; Moyseyev et al., 1980) (Table II.1). Soviet researchers are continuing and expanding on work done in the United States more than 10

**Table II.1**  
**MAGNETOSPHERIC PHYSICS**

(Fields listed in decreasing order of emphasis in the Soviet Union)

- Inner Zone ( $L \lesssim 3$ ) Energetic Particles
- Outer Zone ( $L \gtrsim 3$ ) Energetic Particles
- Precipitation of Energetic Particles
- Plasmapause, Plasmasphere  
(Including Very Low Frequency [VLF])
- Magnetopause, Magnetosheath, Cusp, Boundary Layers
- Solar Particle Access
- Active Space Plasma Experiments
- Solar Wind - Magnetosphere Interactions
- Wave Particle Interactions
- Storms and Substorms
- Electric Fields and Convection
- Magnetosphere - Ionosphere Interactions
- Auroral Phenomena
- Current Systems
- Turbulence
- Magnetotail/Plasma Sheet
- Spacecraft Sheaths and Wakes



years ago, but there are also genuine advances and excellent scientific contributions in areas which have no known US counterparts. In particular, Soviet data on the zones of energetic radiation at low altitudes probably exceed the US database in quality and quantity (Gal'per et al., 1983; Gerberg et al., 1980; Lutsenko and Nikolayeva, 1978). There is a curious inversion of the relative US and Soviet efforts: the maximum Soviet effort appears to be occurring in fields of research more-or-less abandoned by the United States. In contrast, Soviet efforts in fields where the United States is strong and active (solar wind-magnetosphere interactions, magnetosphere-ionosphere interactions) seem comparatively weak. In particular, it is our opinion that the Prognoz program, of long standing and apparently tenaciously pursued, has not made a major contribution to the understanding of the outer regions of the magnetosphere.

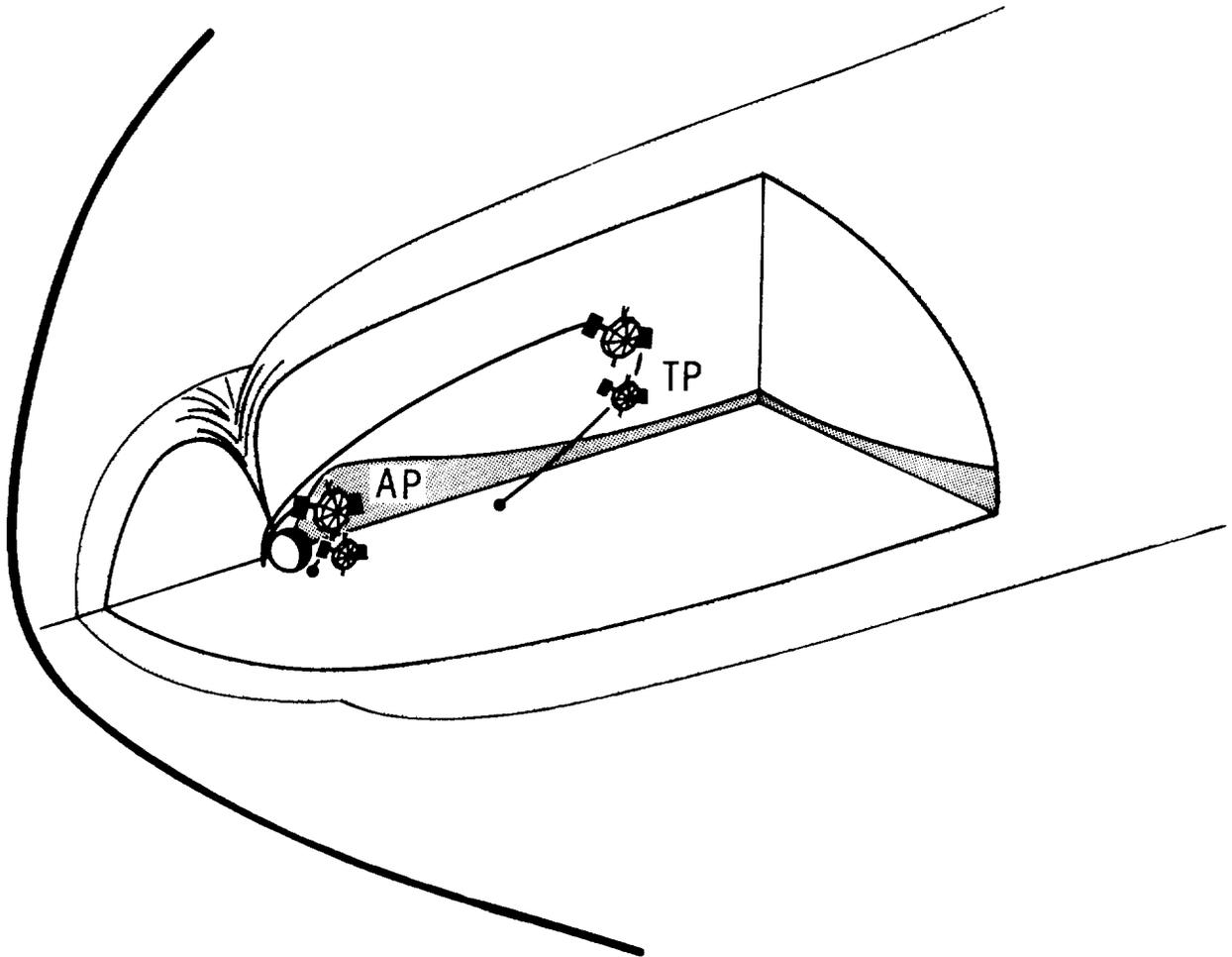
Soviet instrumentation seems adequate, in the physics sense, but lacks the sophistication, provided by microprocessor technology, of US and Western instrumentation. Data presentation seems primitive: phase space distributions and spectrograms are virtually absent. There does not seem to be the kind of integration of data from various instruments aboard a given spacecraft or from multiple spacecraft common to U.S. research in the field. However, there is some very recent evidence--data from Prognoz 10 (launched in April 1985)--that Soviet scientists are making significant progress in incorporating advanced data processing presentation technology into their capabilities.

### **3. Outlook**

Continuation of the Prognoz and Intercosmos programs and rides of opportunity for magnetospheric instrumentation will provide sources of data sufficient to keep the present scope of the Soviet magnetospheric research program moving along. There are also suggestions of other types of missions, illustrated in Figures II.1 through II.4, which would represent a radical departure in the sense of mission complexity from previous Soviet practice. Sketches of Figures II.1 through II.4 were obtained from Academician R. Z. Sagdeyev, Director of the Space Research Institute (Institut kosmicheskikh issledovaniy/IKI) in Moscow, during his last visit to the United States in early 1985, during which he discussed further Soviet plans for space research before various audiences. These missions, if executed, would represent a major improvement in Soviet magnetospheric physics research and would, in several cases, place the Soviet Union ahead of US efforts in the field.

Figure II.1

# Interball



TAIL PROBE (TP):  
+ SUBSATELLITE

ORBIT - 500 km x 250,000 km  
INCLINATION - 65°  
PLASMA SHEET CROSSING  
AT ~120,000 km

AURORAL PROBE (AP):  
+ SUBSATELLITE

ORBIT - 500 km x 20,000 km  
INCLINATION 65°  
AURORAL FIELD LINES  
CROSSING AT ≈10,000 TO 15,000

## Figure II.1 (continued)

- This mission will involve collaboration with France. Launch is expected in 1988.

### TAIL PROBE

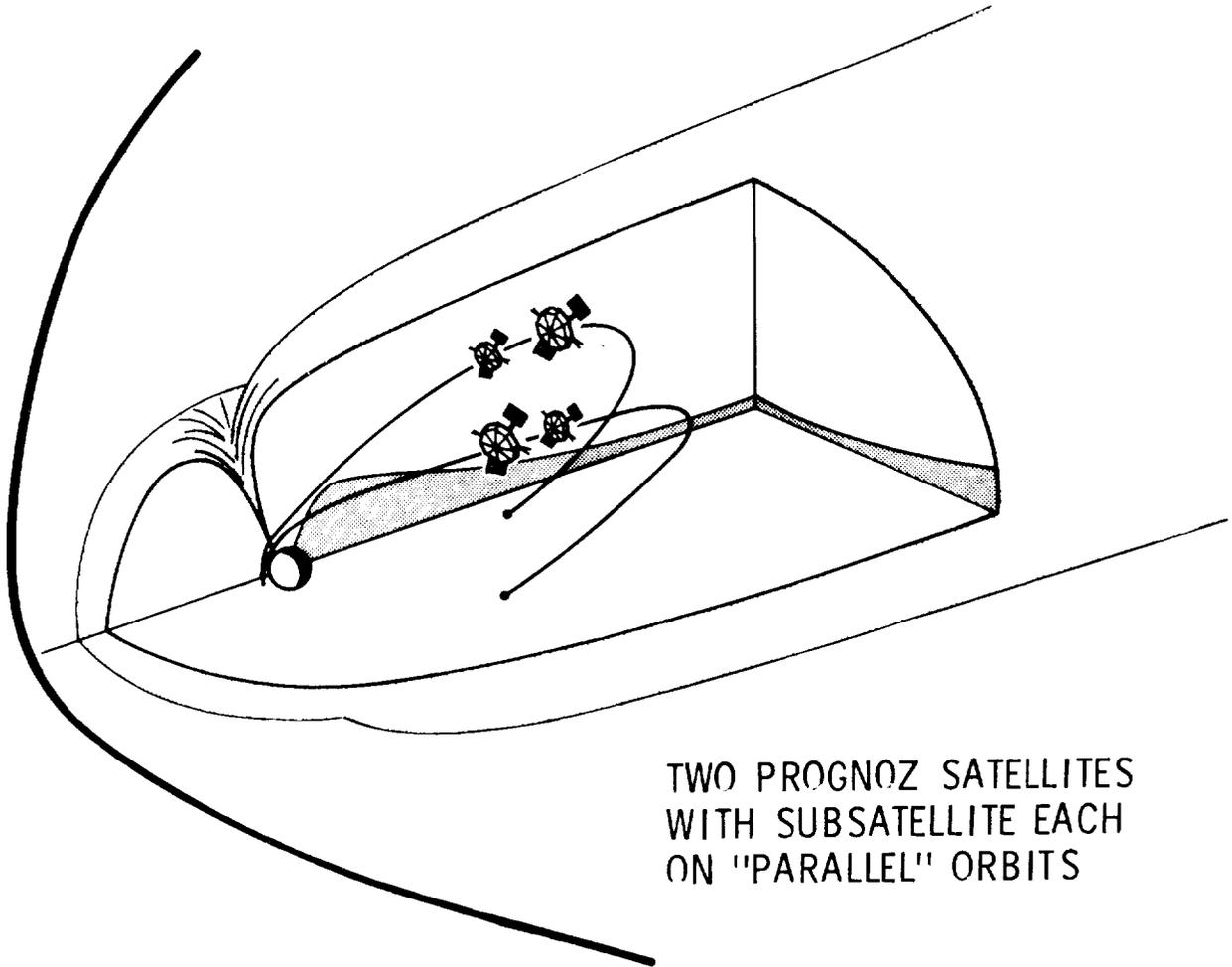
- Fast ( $< 10$  sec) measurements of the three-dimensional particle velocity distribution, magnetic field and plasma waves to study plasma sheet dynamics during substorms.
- On board processor recognizes the signature of the events and organizes the measurements.
- Simple plasma, magnetic field, plasma wave and energetic particle measurements at subsatellite (with orbit-adjust engine) to study spatial structures in the tail (neutral lines, plasmoids, source of accelerated particles).
- Limited solar program.

### AURORAL PROBE

- The measurements of electric and magnetic fields, auroral particles, plasma waves, and parameters of cold plasma to study auroral particle acceleration and auroral kilometric radiation (AKR) mechanisms at altitudes  $\sim 10000$  to  $15000$  km.
- Imaging of auroral oval with scanning photometer.
- Subsateellite ( $\sim 35$  kg), to study the spatial auroral structures (electromagnetic structures of currents and fields, the source of AKR and accelerated particles).
- Onboard processor to organize the specific measurements (reprogrammable from the ground).

Figure II.2

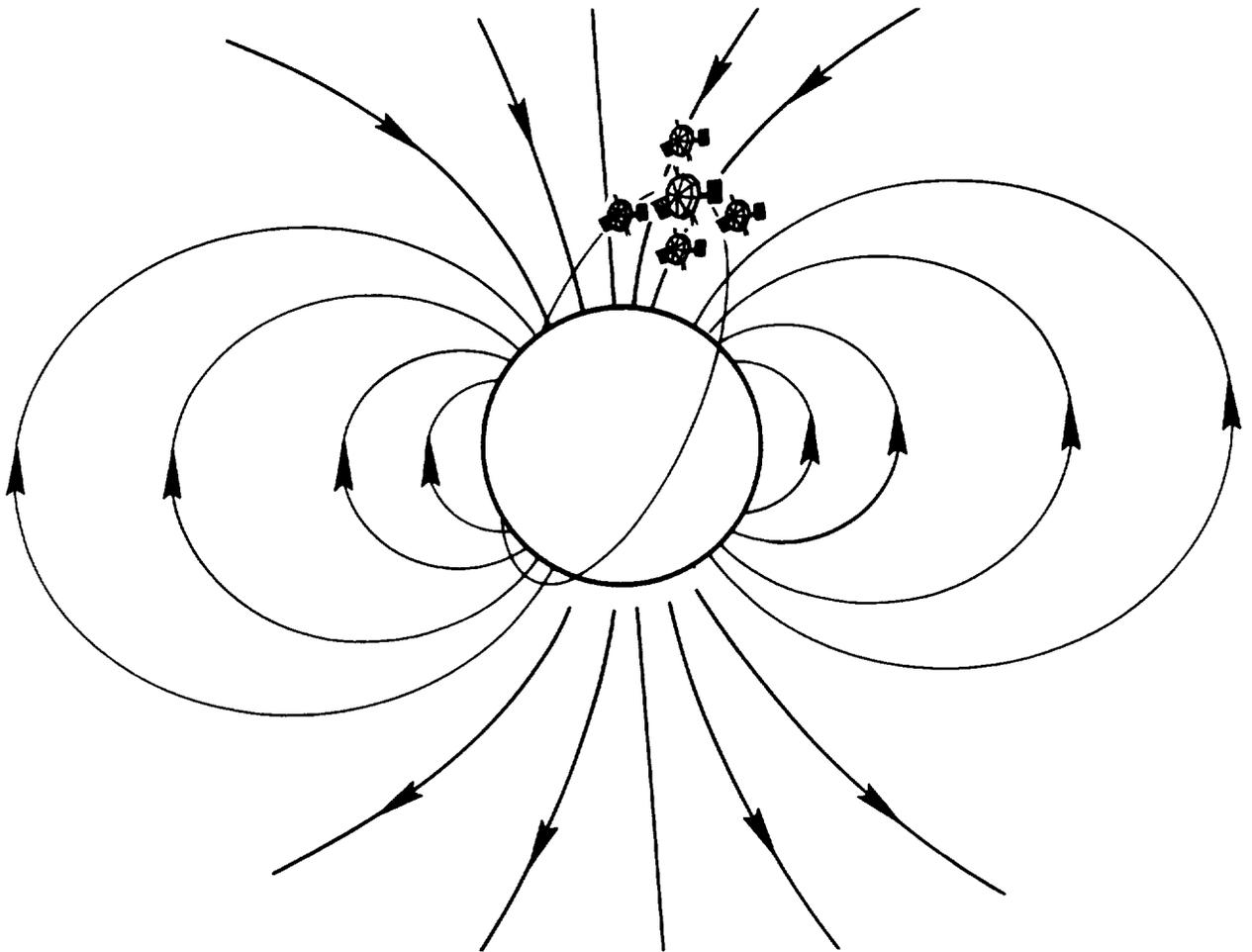
## Future Magnetospheric Mission



1. RADIO SOUNDING TO STUDY GLOBAL PLASMA STRUCTURES  
(DETACHED PLASMA BLOBS NEAR PLASMAPAUSE, PLASMOIDS IN  
THE TAIL ETC.)
2. GAS RELEASE IN THE PLASMA SHEET TO TRIGGER SUBSTORMS
3. LOCAL PLASMA AND FIELDS MEASUREMENTS

Figure II.3

## Low Altitude Auroral Cluster



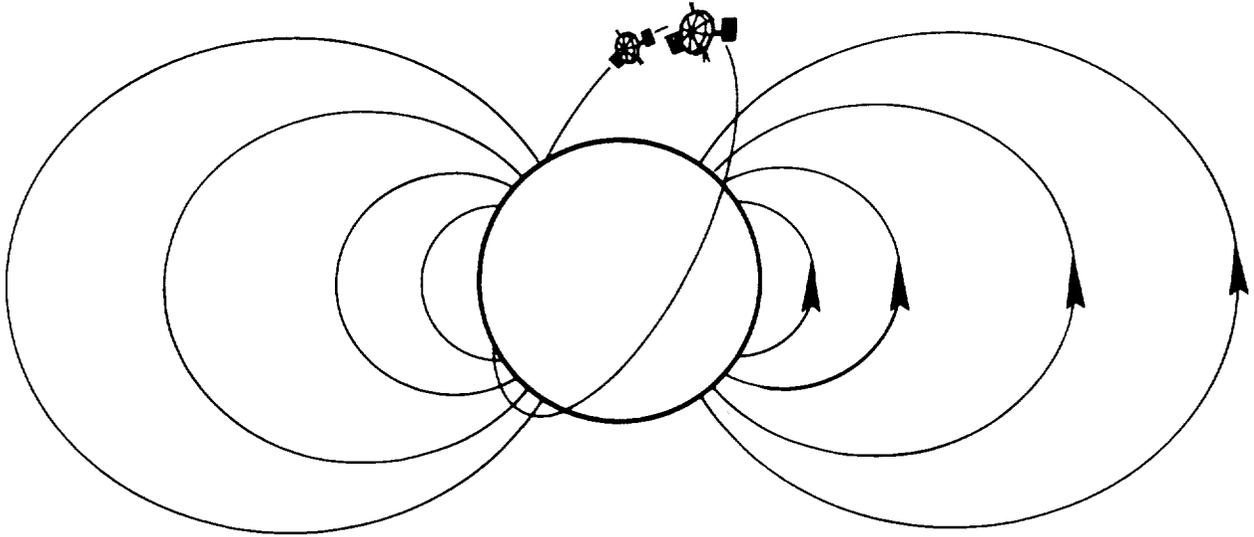
MOTHER SATELLITE + 4 UNORIENTED SPINNING SUBSATELLITES IN  
500 km x 1500 km ORBIT

### OBJECTIVES

- COHERENT ELECTROMAGNETIC STRUCTURES OF AURORAL LONGITUDINAL CURRENTS
- PHYSICS OF IONOSPHERIC ION INJECTION INTO THE MAGNETOSPHERE<sup>F</sup>

Figure II.4

## Active Wave Experiment



SATELLITE IN 500 km x 1500 km ORBIT  
+ SUBSATELLITE OF MAGION TYPE ( $\approx 35$  kg)

- TRANSMITTER: POWER 10 Kw (10% EFFICIENCY)  
FREQUENCY 10 kHz ( $L_{RES} \approx 3$  TO 3,5)
- PLASMA WAVES, ENERGETIC PARTICLES AND COLD PLASMA MEASUREMENTS
  - SPATIAL STRUCTURE OF WAVE DUCTS
  - NONLINEAR DISTORTION OF WAVE SIGNAL  
(AMPLITUDE MODULATION, NONLINEAR FREQUENCY BROADENING, TRIGGERED EMISSION)
  - PARTICLE PRECIPITATION
  - RF HEATING OF PLASMA AND RF DISCHARGE AROUND SATELLITE

## **E. IONOSPHERIC PHYSICS**

### **I. Introduction**

This section describes Soviet research on the physics of the ionized component of the earth's atmosphere. The ionosphere, of course, interacts strongly with the magnetosphere above it and the neutral atmospheric constituents within it, but for the sake of convenience, we have chosen to segregate Soviet research on the ionosphere into one section. This is principally because, as we shall see below, the major thrusts of Soviet work in ionospheric physics appear to deal with:

- issues relating to using the ionosphere as an important element in communications technology, and
- active experiments which attempt to use the ionosphere as a geophysical-scale plasma laboratory.

Hence, the classical use of the term "ionospheric physics" seems most useful.

These two thrusts dominate Soviet ionospheric physics research to a surprising degree. To be sure, there is much work on routine measurements of ionospheric parameters, on ionosphere-magnetosphere interactions, on ionospheric irregularities and instabilities, but, with a few exceptions, the work seems pedestrian and does not contain new or startling insights. One surprising note: there does not seem to be much visible Soviet work on ionospheric forecasting and modeling. The Soviet literature we reviewed was surprisingly weak, both in comparison to the total amount of work going on in ionospheric physics as well as in the context of the rather strong programs in progress in the Soviet Union in solar flare and solar particle event forecasting and modeling.

### **2. State of Research**

#### **a. Ionosphere-Wave Propagation/Communications**

The Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation (Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln) is the leading contributor to research in this field, accounting for about 50% of the work reviewed. A

distant second is the Kola Polar Geophysical Institute (Polyarnyy geofizicheskiy institut). The breadth of the total research program is impressive: ground-based as well as space-based work involving transmission and reception of signals ranging from very low frequency (VLF) to high frequency (HF) is in progress (Pakhotin et al., 1982; Bukin, 1978; Yefimuk et al., 1982; Larkina et al., 1983; Ben'kova et al., 1978a, b). The experimental program appears to be intensive and well executed. A number of the efforts appear to be at least on par with comparable US work, and some avenues of research (for example, HF propagation through magnetospheric paths) (Bukin, 1978; Ben'kova et al.; 1978a, b) apparently have no counterpart in the United States. The theoretical work, although tending toward the abstract, appears better coupled to experimental work in this area than in other areas we reviewed. The heavy dependence of the Soviet Union on HF communication until the relatively recent advent of communications satellites is certainly one of the causes for the massive investment in ionospheric communications-related research. Whether this effort (in the VLF → HF) bands will survive as satellite communication links come to dominate the scene in the future remains to be seen. There is some limited evidence that interest in ionospheric phenomena, such as studies of irregularities important to VHF and ultra-high frequency (UHF) communication channels, is increasing; the principal evidence for this is some work which appears to be attempting to duplicate or replicate US work in this field.

b. Active Experiments

Active experiments, in which scientists attempt to modify the properties of the ionosphere through various means, appear to be of intense interest to Soviet researchers. Research is in progress using a variety of experimental techniques:

- plasma releases from rockets (Andreyeva et al., 1978);
- ground-based ionospheric heaters operating at various frequencies (Bochkarev et al., 1980; Borisov and Gurevich, 1980; Vaskov, 1979);
- electron beam injection from rockets (Izhovkina, 1978; Samokhin, 1978; Volokitin, 1979);
- high power transmitters flown on spacecraft (Gal'perin et al., 1981; Yefimuk et al., 1982);

- analysis of the effects of rocket effluents (Karlov et al., 1980);
- nuclear weapons effects ("pulsed x-ray sources").

The leading institution carrying out this work is the Institute of Terrestrial Magnetism, Ionosphere, and Radio Propagation, with the Lebedev Physics Institute (Fizicheskiy institut imeni P. N. Lebedeva), the Gorky Physics Institute, the Institute for Space Research (Institut kosmicheskikh issledovaniy), and the Kola Polar Geophysical Institute also making important contributions.

The quality of the work seems good, and the variety of experimental efforts reported is impressive, spanning both space-based as well as ground-based techniques. The variety of institutions involved is quite broad, the number of separate authors of papers is large and includes some of the leaders of the Soviet scientific establishment (Sagdeyev, Zhulin). The papers also seem to be rather more timely; the center of gravity of the work (i.e., date of submission) appears to be about 1980.

Some fraction of the work may be connected to attempts to tailor the ionosphere so as to improve or maximize the effectiveness of communications techniques already in place; other work seems to have more general objectives. Coupling to US (or Western) work as indicated by the number of citations is strong in the areas of electron beam injection studies and the effects of rocket engine exhaust on ionospheric properties; on the other hand, in the area of HF heating of the ionosphere, Soviet researchers apparently prefer not to cite comparable work going on in the United States or in Europe.

### **3. Outlook**

One gets the impression that the area of active experiments is one of growth. For example, one of the future mission concepts discussed by Sagdeyev during his 1985 visit to the United States and presented in Figure II.4, appears to be a fairly comprehensive thrust to study wave-particle interaction in the magnetosphere-ionosphere system, as well as a study of the effects of artificially-induced particle precipitation on the ionosphere. There seems to be more zest in the papers, a livelier, less turgid style of writing, less repetition and stern-chasing of US and European efforts. The participation of elements of the scientific leadership of the Soviet Union in this work may be an indicator that this is an area of scientific and technological opportunity.

## F. PHYSICS OF THE UPPER ATMOSPHERE

### 1. Introduction

This section of this assessment presents a review of Soviet work on the physics of the upper atmosphere. By "upper atmosphere" we mean those regions above about 60 km, where the influences of particulate radiations and the variable components of electromagnetic radiation from the sun, as well as particle precipitation from the earth's magnetosphere, cause significant variations in the properties of the atmosphere. The upper atmosphere, as defined in this manner, is thus the "last stop" in the flow of energy originating at the sun.

The earth's upper atmosphere forms a fascinating fluid-dynamical system. Aside from its intrinsic scientific interest, knowledge of the properties of this region of space ( $60 \lesssim h \lesssim 500$  km) is of great practical importance. The ephemerides of low altitude spacecraft are affected by atmospheric density variations, re-entry vehicles experience their maximum heat loads as they traverse this region of space, and space-based surveillance systems must contend with the optical backgrounds which originate, at least in part, in this region of the atmosphere.

### 2. State of Research

In contrast with the massive Soviet literature base we found on magnetospheric and ionospheric physics, the visible Soviet work on the physics of the upper atmosphere seems sparse. The "standard" topics, atmospheric dynamics, atmospheric transmission, radiation, and remote sensing<sup>1</sup> (Solomonov and Khaykin, 1978) are all covered in the literature, albeit thinly. The major concentration of effort appears to lie in the area of atmospheric (mainly thermospheric) modeling (Ramazov et al., 1980, 1982; Gordyets and Kulikov, 1981), although some of the modeling reported has been extended down to  $\sim 20$  km altitude.

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1. "Remote sensing," as used in the present context applies only to the sensing of thermospheric (and related ionospheric) properties. We have not reviewed Soviet work relating to remote sensing of terrestrial (i.e., agriculture, oceanography) signatures.

The modeling work has a distinctly applied flavor (El'yasberg, 1980). The introductory paragraphs of papers make the usual "relevance" bows toward "controlling the motion of spacecraft in the atmosphere" or ". . . nominal trajectories for the motion of airborne equipment." We found that Soviet work makes extensive use of model atmospheres developed principally through US efforts some years ago (CIRA 65, 72; US Standard 1962; Jacchia 77). These models form the basis for modifications and adaptations for particular purposes. Soviet researchers are aware of the Mass Spectrometer/Incoherent Scatter (MSIS) model, but there is no evidence that use has been made of it. (It may be worth noting that the MSIS model, although it represents physical reality considerably more accurately than the models cited above, requires more computational resources for operational utilization--a drawback that delayed adoption of this model in the United States. Similar considerations may apply in the Soviet Union.)

The general state of research in the physics of the upper atmosphere in the Soviet Union is reminiscent of the US state some 12-13 years ago, before such US spacecraft programs as Atmosphere Explorer and others provided an extensive database which is still being digested. Soviet experimental programs in upper atmospheric physics seem limited; for example, there is no evidence of any contribution of indigenous Soviet data to the modeling efforts. We found little evidence of the kind of sophisticated numerical modeling effort which is now common in the United States for research on atmospheric dynamics, atmosphere-ionosphere coupling, and circulation.

### 3. Outlook

One is struck by the fact that Soviet work in the physics of the upper atmosphere is heavily dominated by modeling-related work dealing with developing or improving models of the earth's upper atmospheric density, temperature, wind fields, and radiation. The effort appears to be driven by the practical considerations of developing aids for satellite and re-entry vehicle ephemeris predictions. Soviet work seems to lack an indigenous database and the computer resources which would allow them to capitalize on their well-developed analytical capabilities and access to Western data and model development. Despite the fact that opportunities for improving their database could result from their massive space flight program covering the regions of space of interest, not much progress seems in prospect.

## G. SUMMARY, CONCLUSIONS, AND OBSERVATIONS

The Soviet research program in solar-terrestrial physics is massive, broadly-based, and appears to have considerable momentum--and inertia, in the sense that research areas seem to be pursued well after the cream of the scientific yield has been skimmed. The space flight program is impressive in terms of numbers, not so impressive in terms of scientific yield. Delays between data acquisition and publication have been as long as five to seven years, although there appears to be a shortening of this delay time.

The most impressive portions of the Soviet program are:

- solar event forecasting and solar particle research,
- active experiments in magnetospheric and ionospheric physics, and
- ionospheric radiophysics.

The close connection of these fields of research to the practical requirements suggests that the driving force behind much of the research is application to space system operations (i.e., radiation forecasting and evaluation) and communications forecasting.

The level of instrumentation is primitive by US standards, principally because microprocessor technology has not, until recently, been incorporated into space experiments on the scale common in US practice. The evolution of this technology within the Soviet Union, plus the importation of this technology through cooperative programs with Western nations, should close this gap.

The Soviet space flight program for solar-terrestrial research consists of several components:

- Interplanetary spacecraft carry instrumentation of interest to solar-terrestrial physics.
- The Prognoz and elements of the Intercosmos program are devoted to solar terrestrial physics research.

- Operational spacecraft (communication and military photo-reconnaissance spacecraft) carry instrumentation which yield data of interest to solar-terrestrial physics researchers.
- An occasional Kosmos (example: Kosmos-900) spacecraft appears to be devoted heavily to solar terrestrial physics research.

The Soviet space flight program, as outlined above, appears to be rigid in the sense that the same types of measurements are repeated again and again. However, as described in Section II.D, Soviet planning for future experimentation seems imaginative and fully competitive with US thinking. To be sure, the US ideas date back to the mid-1970's or earlier, but have not yet been executed in an organized way. These comments are meant to suggest that a rapid execution of some of the Soviet ideas noted in Section II.D would make the Soviet Union fully competitive in some very significant portions of solar-terrestrial physics research. One caveat is in order. Multi-spacecraft missions are likely to be very stressing on computation and data analysis resources. If the Soviets do not make major strides in effectively applying computer technology (there does seem to be some limited progress) to the problems of handling the data generated by spacecraft constellations, the only result of flying complex space missions is likely to be an even larger delay time in getting from data to results.

**Table II.2**

**SOVIET INSTITUTIONS CONDUCTING SOLAR-TERRESTRIAL PHYSICS RESEARCH**

Soviet institutions identified in the literature review for this assessment whose members appear to be making significant contributions in research in the various elements of science encompassed by solar-terrestrial physics.

SOLAR PHYSICS

- Gor'kiy Radiophysics Institute, Gor'kiy (Gorky)  
(Nauchno-issledovatel'skiy radiofizicheskiy institut)
- Institute of Applied Geophysics, Moscow  
(Institut prikladnoy geofiziki)
- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation,  
USSR Academy of Sciences, Troitsk/Leningrad  
(Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Lebedev Physics Institute, USSR Academy of Sciences, Moscow  
(Fizicheskiy institut imeni P. N. Lebedeva)
- Moscow State University, Moscow  
(Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova)
- Space Research Institute, USSR Academy of Sciences, Moscow  
(Institut kosmicheskikh issledovaniy)

INTERPLANETARY PHYSICS (PLASMA PHYSICS)

- Institute of Applied Geophysics, Moscow  
(Institut prikladnoy geofiziki)
- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation,  
USSR Academy of Sciences, Troitsk/Leningrad  
(Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Lebedev Physics Institute, USSR Academy of Sciences, Moscow  
(Fizicheskiy institut imeni P. N. Lebedeva)
- Space Research Institute, USSR Academy of Sciences, Moscow  
(Institut kosmicheskikh issledovaniy)

**Table II.2**

**SOVIET INSTITUTIONS CONDUCTING SOLAR-TERRESTRIAL PHYSICS RESEARCH  
(continued)**

INTERPLANETARY PHYSICS (ENERGETIC PARTICLES)

- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences, Troitsk/Leningrad  
(Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Lebedev Physics Institute, USSR Academy of Sciences, Moscow  
(Fizicheskiy institut imeni P. N. Lebedeva)
- Moscow State University, Moscow  
(Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova)

MAGNETOSPHERIC PHYSICS (DISTANT MAGNETOSPHERE)

- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences, Troitsk/Leningrad  
(Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Krasnoyarsk State University, Krasnoyarsk  
(Krasnoyarskiy gosudarstvennyy universitet)
- Moscow State University, Moscow  
(Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova)
- Space Research Institute, USSR Academy of Sciences, Moscow  
(Institut kosmicheskikh issledovaniy)

MAGNETOSPHERIC PHYSICS (SPACE PLASMAS)

- Gor'kiy State University, Gor'kiy (Gorky)  
(Gor'kovskiy gosudarstvennyy universitet imeni N. I. Lobachevskogo)
- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences, Troitsk/Leningrad  
(Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Krasnoyarsk State University, Krasnoyarsk  
(Krasnoyarskiy gosudarstvennyy universitet)
- Moscow State University, Moscow  
(Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova)

**Table II.2**

**SOVIET INSTITUTIONS CONDUCTING SOLAR-TERRESTRIAL PHYSICS RESEARCH**  
(continued)

MAGNETOSPHERIC PHYSICS (SPACE PLASMAS) (continued)

- Siberian Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Siberian Branch, USSR Academy of Sciences, Irkutsk (Sibirskiy institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Space Research Institute, USSR Academy of Sciences, Moscow (Institut kosmicheskikh issledovaniy)

MAGNETOSPHERIC PHYSICS (ENERGETIC PARTICLES)

- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation USSR Academy of Sciences, Troitsk/Leningrad (Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Moscow State University, Moscow (Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova)

MAGNETOSPHERIC PHYSICS (SOLAR PARTICLE ACCESS)

- Institute of Applied Geophysics, Moscow (Institut prikladnoy geofiziki)
- Krasnoyarsk State University, Krasnoyarsk (Krasnoyarskiy gosudarstvennyy universitet)
- Moscow State University, Moscow (Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova)

IONOSPHERIC AND MAGNETOSPHERIC PHYSICS (ACTIVE EXPERIMENTS)

- Gor'kiy Radiophysics Institute, Gor'kiy (Gorky) (Nauchno-issledovatel'skiy radiofizicheskiy institut)
- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences, Troitsk/Leningrad (Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Irkutsk State University, Irkutsk (Irkutskiy gosudarstvennyy universitet imeni A. A. Zhdanova)

**Table II.2**

**SOVIET INSTITUTIONS CONDUCTING SOLAR-TERRESTRIAL PHYSICS RESEARCH**  
(continued)

IONOSPHERIC AND MAGNETOSPHERIC PHYSICS (ACTIVE EXPERIMENTS)  
(continued)

- Lebedev Physics Institute, USSR Academy of Sciences, Moscow  
(Ficheskiy institut imeni P. N. Lebedeva)
- Polar Geophysical Institute, Kola Branch, USSR Academy of Sciences,  
Apatity (Polyarnyy geofizicheskiy institut)
- Space Research Institute, USSR Academy of Sciences, Moscow  
(Institut kosmicheskikh issledovaniy)

IONOSPHERIC PHYSICS

- Arctic and Antarctic Scientific Research Institute, Leningrad  
(Arkticheskiy i antarkticheskiy nauchno-issledovatel'skiy institut)
- Gor'kiy Radiophysics Institute, Gor'kiy (Gorky)  
(Nauchno-issledovatel'skiy radiofizicheskiy institut)
- Institute of Applied Geophysics, Moscow  
(Institut prikladnoy geofiziki)
- Institute of Geophysics, Academy of Sciences, Georgian SSR, Tbilisi  
(Institut geofiziki)
- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation,  
USSR Academy of Sciences, Troitsk/Leningrad  
(Institut zemnogo magnetizma, ionosfery i rasprostraneniya radiovoln)
- Krasnoyarsk Computer Center, Siberian Branch, USSR Academy of Sciences,  
Krasnoyarsk  
(Vychislitel'nyy tsentr)
- Moscow State University, Moscow  
(Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova)
- Polar Geophysical Institute, Kola Branch, USSR Academy of Sciences,  
Apatity  
(Polyarnyy geofizicheskiy institut)

**Table II.2**

**SOVIET INSTITUTIONS CONDUCTING SOLAR-TERRESTRIAL PHYSICS RESEARCH**  
(continued)

IONOSPHERIC PHYSICS (RADIO WAVE PROPAGATION)

- Institute of Applied Geophysics, Moscow  
(Institut prikladnoy geofiziki)
- Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation,  
USSR Academy of Sciences, Troitsk/Leningrad  
(Institut zemnogo magnetizma, ionosfery i rasprostraneniya radio voln)
- Leningrad State University, Leningrad  
(Leningradskiy gosudarstvennyy universitet imeni A. A. Zhdanova)
- Polar Geophysical Institute, Kola Branch, USSR Academy of Sciences,  
Apatity  
(Polyarnyy geofizicheskiy institut)

PHYSICS OF UPPER ATMOSPHERE

- Institute of Experimental Meteorology, Obninsk  
(Institut eksperimental'noy meteorologii)
- Institute of Atmospheric Physics, Moscow  
(Institut fiziki atmosfery)
- Lebedev Physics Institute, USSR Academy of Sciences, Moscow  
(Fizicheskiy institut imeni P. N. Lebedeva)



## CHAPTER II: SOLAR-TERRESTRIAL PHYSICS

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**CHAPTER III**  
**LUNAR AND PLANETARY SPACE RESEARCH:**  
**1975-1985 AND FUTURE PROGRAMS**

**A. INTRODUCTION**

The Soviet lunar and planetary research program, based on a commitment to achievement and maintenance of scientific leadership in selected (rather than general) areas, is outstanding. Table III.1 indicates the magnitude and nature of this commitment to explore the Moon, Mars, and Venus over the period 1959 through 1985. The Soviet program is highly innovative, with much continuity in designated science objectives, and the many flights provide multiple opportunities to introduce new and improved measurement techniques. Although only a few planetary targets are available for the Soviet missions, their program actually is very broad, including analysis of planetary interiors, surfaces, and atmospheres, as well as the plasma environment and plasma dynamics. Some of the space missions are apparently constrained by booster performance, but those missions that are selected are well supported with strong theoretical and laboratory investigations. Some Soviet data analysis programs have been relatively weak in the past, but even these are now improving significantly from earlier low levels.

Other dramatic areas of change in recent years are related to the improved performance of the Soviet planetary spacecraft (longer lifetimes, higher data rates, etc.) and the increasing assurance that the missions will be successful. In association with these changes, the Soviet Union now participates quite openly in cooperative planning ventures with the European Space Agency (ESA) and individual European countries and institutions, and even the United States and Japan (via the Interagency Consultative Group). Payload, launch date, spacecraft, and trajectory information are freely disseminated in advance, and Western scientists (including a few from the United States) participate actively in the Soviet planetary missions. US scientists routinely cooperate in the data analysis and in some aspects of mission planning (e.g., selection of Venus landing sites).

**Table III.1**  
**SOVIET LUNAR AND PLANETARY MISSIONS THROUGH 1985**

<u>Payload Name</u>	<u>Launch Date</u>	<u>Payload Name</u>	<u>Launch Date</u>
Luna 1 (Mechta)	2 Jan 1959	Luna 14	7 Apr 1968
Luna 2	12 Sep 1959	Zond 5	14 Sep 1968
Luna 3	4 Oct 1959	Zond 6	10 Nov 1968
Venera 1	12 Feb 1961	Venera 5	5 Jan 1969
Mars 1	1 Nov 1962	Venera 6	10 Jan 1969
Luna 4	2 Apr 1963	Luna 15	13 Jul 1969
Zond 1	2 Apr 1964	Zond 7	7 Aug 1969
Zond 2	30 Nov 1964	Venera 7	17 Aug 1970
Luna 5	9 May 1965	Luna 16	12 Sep 1970
Luna 6	8 Jun 1965	Sample Returner	21 Sep 1970 (from Moon)
Zond 3	18 Jul 1965	Zond 8	20 Oct 1970
Luna 7	4 Oct 1965	Luna 17	10 Nov 1970
Venera 2	12 Nov 1965	Kosmos 419	10 May 1971
Venera 3	16 Nov 1965	Mars 2-Orbiter	19 May 1971
Luna 8	3 Dec 1965	Mars-Lander	19 May 1971
Luna 9	31 Jan 1966	Mars 3-Orbiter	28 May 1971
Luna 10	31 Mar 1966	Mars 3-Lander	28 May 1971
Luna 11	24 Aug 1966	Luna 18	2 Sep 1971
Luna 12	22 Oct 1966	Luna 19	28 Sep 1971
Luna 13	21 Dec 1966	Luna 20	14 Feb 1972
Venera 4	12 Jun 1967	Sample Returner	22 Feb 1972 (from Moon)
Zond 4	2 Mar 1968		

**Table III.1**  
**SOVIET LUNAR AND PLANETARY MISSIONS THROUGH 1985**  
(continued)

<u>Payload Name</u>	<u>Launch Date</u>	<u>Payload Name</u>	<u>Launch Date</u>
Venera 8	27 Mar 1972	Luna 24	9 Aug 1976
Luna 21	8 Jan 1973	Sample Returner	19 Aug 1976 (from Moon)
Mars 4	21 Jul 1973		
Mars 5	25 Jul 1973	Venera 11-Orbiter	9 Sep 1978
Mars 6-Orbiter	5 Aug 1973	Venera 11-Lander	9 Sep 1978
Mars 6-Lander	5 Aug 1973	Venera 12-Orbiter	14 Sep 1978
Mars 7-Orbiter	9 Aug 1973	Venera 12-Lander	14 Sep 1978
Mars 7-Lander	9 Aug 1973	Venera 13-Orbiter	30 Oct 1981
Luna 22	29 May 1974	Venera 13-Lander	30 Oct 1981
Luna 23	28 Oct 1974	Venera 14-Orbiter	4 Nov 1981
Sample Returner	None	Venera 14-Lander	4 Nov 1981
Venera 9-Orbiter	8 Jun 1975	Venera 15	
Venera 9-Lander	Jun 1975	Venera 16	
Venera 10-Orbiter	14 Jun 1975	VEGA 1	
Venera 10-Lander	14 Jun 1975	VEGA 2	

Adapted from pp. 160-163, Planetary Exploration Through the Year 2000, Part I of a report by the Solar System Exploration Committee of the NASA Advisory Council, NASA, 1983.

The expansion in the Soviet planetary program comes during a period when the US planetary program is struggling to survive with a drastically constrained series of proposed missions. Following the great successes of the Viking Mars orbiter/lander missions in 1976, the Pioneer Venus orbiter/lander mission in 1978, and the Voyager Jupiter flyby missions in 1979, many critics clamored for reduction or even termination of the US program. NASA appointed the Solar System Exploration Committee (SSEC) to design a constrained program, and this group came up with a series of missions having limited science payloads and restricted science objectives. Even the largest spacecraft contemplated in these US plans (the Mariner Mark II) were only designed to accommodate five to eight science instruments, and one way to compare Soviet plans with corresponding US concepts involves a comparison of prospective science payloads.

In a certain real sense, the Soviet lunar and planetary programs have been at times complementary to those of the United States, and direct head-to-head confrontations have occurred at various times. Examples of this are readily noted:

- Venera 15, 16 mapped the high latitude regions that will not be very well covered by the US Venus Radar Mapper mission.
- While the US Mars Observer mission will concentrate on Mars climatology and atmospheric dynamics, the Soviet Mars mission for the same time period will concentrate on characteristics of Phobos (and Deimos?) and on the solar-wind interaction with Mars.

However, the plans for the Soviet Lunar Orbiter seem to be in direct conflict with the NASA-SSEC (Solar System Exploration Committee) plans for a similar mission in the Observer program. Some observers interpret this challenge as a signal that the lunar mission would be a suitable candidate for a joint US-Soviet space research project, if the United States is willing. Otherwise, the Soviets will "go it" alone.

## **B. PAST AND CURRENT STATUS**

### **1. Venera 9, 10**

The Venera 9, 10 spacecraft were the first of a new series of "second generation automatic spacecraft," and this basic design has been utilized, with some changes, for all

subsequent Venus exploration to date (Venera 11, 12, 13, 14, 15, 16, VEGA 1, 2). Apparently there is only one more version of this spacecraft and it is scheduled to be used for another earth orbiting astronomy mission (an '87 to '88 launch). Because the Venera 9 to VEGA 2 missions represent elements of a unified program, it seems appropriate to discuss all of these missions together.

Venera 9, 10 were a pair of orbiters (O) and soft landers (L) that arrived at Venus in October 1975. The orbiters had an apoapsis of about  $19 R_V$ , and periapsis altitude of about 1600 km. Thus, they were well suited to study the distant plasma tail and wake of Venus, but there were no in situ measurements of the main solar wind interaction with the Venus ionosphere, which develops much closer to the planet. The payloads were as follows:

- Surface Imaging (L)
- Cloud Nephelometer (L)
- Atmospheric Structure--Pressure (P), Temperature (T) (L)
- Cup Anemometer--Wind (L)
- Narrow-band Photometer (CO<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O content) (L)
- Wideband Photometer; 0.5-1 Micrometer (L)
- Magnetometer (O)
- Photopolarimeter (O)
- Plasma Spectrometer; Curved Plate Analyzer (O)
- Faraday Cup Plasma Probe (O)
- IR Radiometers; 7.4-30 micrometer (O)
- UV Lyman-Alpha (O)
- UV Photometers (O)
- 3000-8000 Angstrom Spectrometers (O)
- Cloud Imaging (UV and visible [V] cameras) (O)
- Radio Science (8 and 32 cm) (O)
- Mass Spectrometers (L)

The initial scientific results from the Venera 9, 10 investigations started to appear in the Soviet journal, Kosmicheskiye issledovaniya (Cosmic Research), in the January-February issue of 1978 (Vol. 16) and continued in issues throughout that year and through much of 1979. This Venera mission provided first-order information on the surface and atmosphere of the planet, the clouds, and the solar wind interaction. The literature

shows that Soviet scientists are still analyzing data from Venera 9, 20; however, with the exception of some theoretical studies, most of the post-1979 publications involve comparisons with data from Pioneer Venus or later Venera spacecraft.

Venera 9, 10 plasma probes and magnetometers gave important new information on plasma flow in the sheath, mantle or boundary layer, and distant tail or wake (Dolginov, 1978; Gringauz et al., 1976; Vaysberg et al., 1976). However, the orbiters did not yield definitive knowledge about the existence of an intrinsic planetary magnetic field.

An orbiter optical instrument (3000-8000 Angstrom Units) detected a very intense flash coming from the Atla region east of Aphrodite. This was originally interpreted in terms of thunderstorm activity, but several years later (after the Pioneer Venus wave investigation indicated that the Atla region was a potential source of volcanic lightning, and after the Pioneer ultra-violet investigation showed changing levels of sulphur dioxide), it was conjectured that this might have been caused by a volcanic eruption (Ksanfomaliti, 1984).

The lander cameras provided the first pictures of the Venus surface. These remarkable images yielded a wealth of important new information about Venus, and they enhanced the concept of volcanism as an intrinsic aspect of Venusian dynamics (Florenskiy et al., 1983; see also the discussion of Venus surface characteristics in Section III.C, "United States-Soviet Union Comparison," below).

The Venera 9, 10 landers carried the first mass spectrometers to the surface of Venus, but it appears that the inlet systems did not function correctly (see discussion by Von Zahn et al. in Venus [1983], pp. 319, 320). However, useful atmospheric measurements of temperature, pressure, and density were obtained (Avduyevsky et al., 1983). Other Venera 9, 10 lander investigations utilized broad and narrowband photometers. Sagdeyev, Moroz, and Breus (1983) summarized the results and interpretation.

The first detailed information on the layered structure and physical characteristics of the Venus clouds came from the Venera 9, 10 nephelometers (Marov 1978, 1980).

## 2. Venera 11, 12

The orbiters were replaced by flyby spacecraft to lengthen transmission time from the surface, and the lander payloads were improved. The (functioning) payloads were as follows:

- Bennett Mass Spectrometers (L)
- Gas Chromatograph (L; Venera 12)
- Atmospheric Structure--P, T, Accelerometer (L)
- Scanning Spectrophotometer: 0.45-1.2 microns (L)
- Nephelometer (L; Venera 11)
- X-ray Fluorescence Spectrometer (L; Venera 11)
- Electric Discharges-Waves (L)
- UV Spectrometer; 300-1650 Angstroms (Flyby)
- Solar Wind/Planetary Plasma (Flyby)
- Energetic Particles (Flyby)
- Gamma Ray Bursts (Flyby)
- Radio Science; Wind Speed from Doppler Analysis

The preliminary scientific results from the mission were summarized in a special issue of Kosmicheskiye issledovaniya (Cosmic Research, 21, 5, [1979]), and Sagdeyev, Moroz, and Breus (1983) provided another summary.

The Venera 11, 12 Bennett-type mass spectrometers plus gas chromatograph(s) provided very significant new information on the composition of the lower atmosphere (< 50 km), but comparisons of data from the two types of instruments on the Venera landers and the Pioneer Venus probes showed serious discrepancies that prompted considerable joint analysis. The first discrepancy involved the detection of krypton on Venera (Istomin et al., 1979), and subsequently, it was shown that the results from the Mukhin's gas chromatograph (Gel'man et al., 1979) differed substantially from the Pioneer Venus results in terms of oxygen and water vapor content. The US chromatograph data were later shown to be in error (see discussion by Sagdeyev, Moroz, and Breus, 1983), but the mass spectrometer problems were harder to resolve (Istomin et al., 1982; Mukhin, 1983).

Venera 11, 12 carried wave analyzers with search coil sensors, and they detected many strong and impulsive signals during the descent. These were interpreted as radiation from lightning and joint Venera-Pioneer Venus Orbiter (PVO) studies of lightning were subsequently carried out (Ksanfomaliti, 1979; Ksanfomaliti, Scarf, and Taylor, 1983).

The landers provided improved measurements of the solar radiation flux and spectrum as a function of altitude.

The Venera 12 x-ray fluorescence spectrometer (Surkov et al., 1981) represented a new type of measurement and the results were somewhat surprising, with chlorine identified as the primary element for some of the clouds.

### **3. Venera 13, 14**

These flyby-lander missions carried out remarkable solid analysis experiments, and they provided the first imaging at a definite volcanic site, as well as the first color images from the surface of Venus. Figure III.1 shows black and white versions of the Venera 14 images.

- Color Imaging (L)
- Nephelometer (L)
- Electric Discharges-Waves (L)
- Soil Sample Scoop Device (L)
- Seismometers (L)
- Wind Speed from Doppler Analysis (L)
- Wind Speed from Acoustic Analysis (L)
- Accelerometers; Pressure, Temperature (L)
- Gas Chromatographs (L)
- Optical Spectrophotometer (L)
- X-ray Fluorescence Spectrometers (L)
- (Soil + Cloud Analysis)
- Mass Spectrometers (L)
- Water Vapor Detector-Hygrometer (L)
- UV Photometers: 0.32-0.39 microns (L)

Figure III.1  
VENERA-14 SURFACE IMAGE



ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС



ВЕНЕРА-14 ОБРАБОТКА ИППИ АН СССР И ЦДКС

- Magnetometer (Flyby)
- Plasma Probes (Flyby)
- Solar Protons (1-30 MeV); Cosmic Rays (Flyby)
- Gamma Ray Bursts (Flyby)
- Two-Frequency Radio Science (Flyby)

If we simply examine the number of instruments listed in this table, we conclude that the Soviet program has reached a very impressive stage of competence. The largest US Pioneer atmospheric probe had only seven science instruments.

In most cases the lander instruments were greatly improved with respect to the previous missions. For instance, Sagdeyev and Moroz (1982) stated that the sensitivity of the Venera 13, 14 mass spectrometers was 10-30 times greater than in the previous flight. The detailed results from the landers have been summarized in a special issue of Kosmicheskiye issledovaniya (Cosmic Research, 21, 3 [1983]) and by Moroz (1983) (see also, Ksanfomaliti, 1983, and Ksanfomaliti et al., 1983). However, very little has emerged from the observations carried on the flyby spacecraft; it is likely that there was very little tracking for these spacecraft.

The Venera 13 and 14 soil-scooping mechanisms (Barmin and Shevchenko, 1983) allowed detailed analysis of the rock composition. Surkov et al. (1983) described the ingenious mechanism, the detailed data analysis program, and the initial results.

#### 4. Venera 15, 16

These orbiters provided the first high resolution (order of one kilometer) radar maps of the Venus surface, and the payload also included IR thermal emission spectrometers. The spacecraft were modified Venera-class, with 1.4-meter by six-meter side-looking radars mounted where the landers are normally placed. These missions were remarkable in terms of the new science return. Some high-resolution radar images have been published in Volume IV of the Planetary Report (6 [1984]) along with descriptions furnished by V. Barsukov. The images show lava plains, highlands with multiple ridges and valleys, tectonic dislocations, and the folding zones formed by intensive tectonic processes.

## 5. VEGA 1, 2

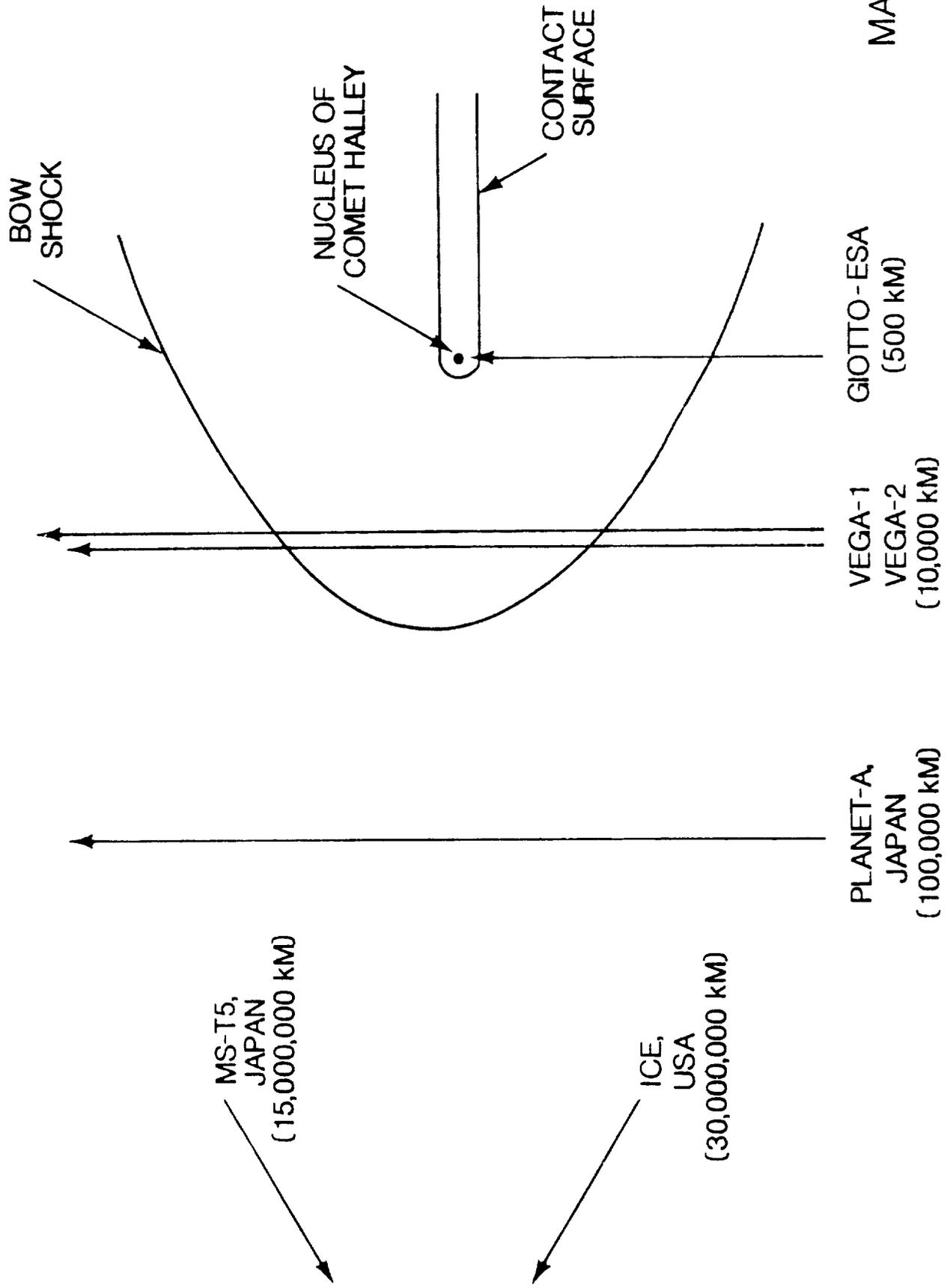
These spacecraft encountered Venus in June 1985, on their way to Halley's Comet. They carried the first upper atmosphere balloons instrumented to study upper atmospheric winds, pressure and temperature, and cloud structure; a balloon-borne optical sensor has been described as a device to search for lightning flashes and as a luminosity detector. The landers, which came down at night on the Aphrodite highlands, did have optical lightning detectors. These missions involved the first direct cooperation with the United States in a planetary mission (DSN [Deep Space Network] tracking; US hardware and designs plus US co-investigators associated with Western European and Hungarian instruments). The balloons and landers arrived at Venus in June of 1985, and the initial results have been discussed informally. Apparently, both VEGA balloons operated successfully for more than 40 hours as they drifted past the terminator into sunlight (the lifetimes were limited by battery power), but definitive reports on the landers are not yet available; the VEGA 1 lander was said to have operated for about 20 minutes on the surface, and there are reports of a premature deployment of one of the soil sample collectors. Some initial reports suggest that a VEGA 2 optical instrument detected visible evidence of lightning flashes near Atla, consistent with the Pioneer Venus conjectures of an intense lightning occurrences near this surface feature, but this conjecture has apparently been abandoned.

## 6. Primitive Bodies

The Soviets are leading the way in the analysis of comet phenomena with the VEGA mission to Comet Halley. This mission involves important departures from past practices (in terms of cooperation with Western Europe and even the United States, prior disclosure of spacecraft, mission and instrument details) and a great increase in scientific sophistication. (Although the VEGA spacecraft are basically Venera 9, 10-type designs, for the risky high-speed [80 km/sec] comet encounter they have been outfitted with dust shields and high-resolution fast [CCD] imaging systems that have image-motion compensation capabilities.)

The VEGA 1 and 2 spacecraft are part of an international cooperative effort to study Halley's Comet in 1986, and Figure III.2 shows the trajectories for the six flybys. Only the VEGA and ESA Giotto spacecraft have cameras, and since VEGA is three-axis stabilized, it promises to provide the best (as well as the first) pictures of a comet

Figure III.2  
 TRAJECTORIES FOR 1986 ENCOUNTERS WITH HALLEY'S COMET



nucleus. Giotto is a spin-stabilized spacecraft with a more limited imaging system that can achieve VEGA-class imaging only when it is within a few hundred kilometers of the nucleus. The Giotto imaging success depends on survival to close distances, as well as excellent navigation. In fact, the Soviet Union and the United States are cooperating in the so-called Pathfinder Project to improve the Giotto navigation with respect to Halley's nucleus. The VEGA pictures of the nucleus will tell where the object is with respect to the Soviet spacecraft, and the NASA Deep Space Net will track VEGA to provide highly accurate position information; these measurements will be furnished to ESA to reduce the Giotto navigation error.

The VEGA science payload is by far the most comprehensive and most international of any for the Halley encounters. In addition to imaging, each VEGA has a French infrared spectrometer (2.5 to 12 micrometers), a Soviet-Bulgarian-French three-channel spectrometer (120-1800 nanometers), a Soviet-West German-French dust-impact mass analyzer, a West German neutral gas mass spectrometer, a Soviet-Austrian magnetometer, a Soviet-Hungarian-West German plasma probe, a Soviet-Hungarian-West German energetic particle detector, a Polish-Czechoslovakian-French-Soviet plasma wave investigation, a Soviet dust particle detector, a Soviet electro-optic dust analyzer, and a Hungarian-West German-Soviet dust particle counter. For VEGA the international involvement is very significant, and the International Scientific and Technical Committee of the VEGA Project, which is chaired by R. Sagdeyev, has two French scientists (R. Pellat and F. Sabo) as vice-chairmen. Other members of this committee include representatives from Austria, Bulgaria, Hungary, East Germany, West Germany, and Czechoslovakia. In addition, several US scientists are serving as unofficial co-investigators on VEGA, and some US instrument designs (and even hardware) are on these spacecraft. Details of the mission have been circulated in a book (Venus-Halley Mission) published by the above-mentioned committee.

The Soviet effort in the area of primitive bodies is not exclusively represented by the VEGA mission. On Salyut 7, the cosmonauts had equipment for comet imaging that was successfully used to take pictures of Comet Crommelin, as practice for planned Salyut imaging of Halley. There have also been extensive theoretical efforts to study the plasma instabilities that control important aspects of comet-solar wind interactions (Galeyev et al., 1985), together with laboratory simulations of the interaction (Dubinin et al., 1980).

## **7. Mars**

Here the recent efforts have focused on magnetospheric data analysis and theory. There have been no fresh data since the Mars missions of the early 1970's, but a significant analysis program has continued. Dolginov (1978) re-analyzed the magnetometer data from Mars 2, 3, and 5 and constructed a more more modern model of the Martian magnetosphere. Other studies focused on the heavy ion spectra (Vaisberg and Smirnov, 1978), the configuration and nature of the magnetosphere (Smirnov, et al., 1978, Breus and Gringauz, 1980) and the possible plasma effects from Deimos (Bogdanov, 1978). Krasnopol'skiy et al., (1980) have continued to construct atmospheric models using data from the Mars series of orbiters. Additional scientific papers have used data from the Mariner and Viking orbiters or measurements from the Viking landers (Krasnopol'skiy, 1980).

## **8. The Moon**

The last Soviet lunar mission (Luna 24) returned its sample to Earth on 19 August 1976, and the research during the past decade has been largely concerned with continued analysis of the samples, along with theory. Drupenio (1976 a, b) has also tried to evaluate lunar surface characteristics using Luna radar data.

## **9. Outer Planets**

The Soviets have not attempted any outer planets missions, but their scientists have shown a keen interest in outer planets research. It is likely that several factors combine to make such a mission impractical or impossible. These include the long trip times, the large launch energy requirements, the tracking difficulties over great distances, the need for mission-unique spacecraft with new thermal requirements, nuclear power sources, etc., and the large cost for such a mission, which would certainly not be based on the use of an existing earth-orbiter design.

There have been significant Soviet contributions in the area of Jupiter magnetosphere analysis; coupling of the Io torus with the Jovian magnetosphere (Galeyev and Chabibrachmanov, 1982; Galeyev, 1983) and the Titan torus with the Saturn magnetosphere (more Alfven mechanism application).

## C. UNITED STATES-SOVIET UNION COMPARISON

### 1. Venus

The US program (Pioneer Venus Orbiter and Probes, plus the Venus Radar Mapper, planned for launch in 1988) and the Soviet program for essentially the same time period (Venera 11, 12, 13, 14, 15, 16, plus VEGA 1, 2) are fairly complementary, and each side has an impressive list of "firsts." If we ignore questions of priority in time, then one might ask if the programs could be regarded as comparable, and the answer is that the Soviet program is so active and innovative on so many distinct scientific fronts that present Soviet leadership at Venus must be acknowledged. The Soviets have had a great many opportunities to advance their science with new instruments and new missions, and they have taken full advantage of this to obtain a lead that may well be insurmountable. For instance, by the time the US Venus Radar Mission starts to provide extremely important new science in a planetary region that is full of fascinating surface features, the Soviet program will be moving on from the prior successes of VEGA 1, 2 (as well as Venera 15, 16) to the Vesta missions, and their lead probably will widen (see below).

The Soviet program is especially far along in the area of surface science.

There are colored panoramic images of layered rocks at surface at Venera Landing Sites 13 and 14. There are earlier panoramic images at Venera Sites 9 and 10. Thin layers are interpreted as volcanoclastic (explosive eruptions) rocks (i.e., layered tuffs), in contrast to US papers that claim that the pressure is too great for the degassing that forms these types of rocks. An alternate US view is that these are flow layered basalts. These contrasting interpretations are impossible to settle with the present data. The Soviet color reconstructions of surface panoramic images show rocks as orange, presumably due to oxidation of dark iron bearing minerals. However, the color bar reconstruction on the spacecraft at the surface does not look correct. Recent US recalibration of the color indicates that the proper color is yellow-gray, perhaps indicating lesser oxidation in this area. The surface chemistry shows tholeiitic basalt in the lowland and high potassium basalt up on the flank of the volcanic construct. These results are similar to analyses in Columbia Plateau in Washington, or in Hawaii. This major element chemistry is from x-ray fluorescence observations made on a sample brought into the spacecraft. Earlier chemistry is gamma ray spectrometer data of surface material; this instrument can only measure radioactive uranium, thorium, and potassium. Veneras 9 and 10 lie on

the east flank of the Beta Region volcanic constructs, and the rocks are interpreted to be basalts. This interpretation is wholly consistent with the morphology (shape) of the mountains. The earlier Venera 8, that landed to the east, measured a "syenite"--that is, a rock high in potassium, aluminum, and silicon. This interpretation was consistent with the US data from the Pioneer Venus Orbiter showing this area as upland rolling plains with a composition that might be like lunar uplands. With the high potassium basalts in Venera 13, it is by no means certain that the Venera 8 site does not contain similar high potassium basalt in a local volcano, and we do not know the composition of the widespread rocks that form 65% of the Venus crust. Table III.2 shows the chemical results. Venera 15 and 16 orbital radar images with resolution of one to three km from near periapsis to the northern and southern ends of the swaths; they are shown in a computer mosaic. One altimeter profile across Maxwell Montes that agrees well with US Pioneer Venus data has been shown, but it has twice the data spacing so more detail is visible. Also, the Soviets have indicated that error is 50 meters rather than the 100 meters that is the measurement limit of the US data. The preliminary interpretation of the Soviet radar images in the north polar cap region of Venus (about 30% of the planet) shows a more complex geologic history than could be derived from the US Pioneer Venus data and the US ground-based radar images. A spectacular series of ridges and valleys that surround the Lakshmi plateau look like they were formed by compressional tectonic activity. Also striking are bands of "cross hatched" terrain that look like fault blocks, indicating contrasting extensional tectonics. This style would fit with the many rift valleys observed in the Pioneer Venus and earth-based US data. The smooth, uncratered lowland plains are strikingly shown, as are the rolling upland plains with many ovoid features. These were previously interpreted as possible impact craters, but these high-resolution data show complex structures that may be like very ancient structures formed by magmatic activity in the early Earth's crust. Many volcanic constructs, large and small, and elongated volcanic vents are shown as well as many small circular crater forms. These are interpreted as impact craters by the Soviets, but they may be either impact or volcanic in particular cases.

The early hand-laid mosaics with strong marginal shadows indicate that the antenna pattern has not been removed yet. No formal mosaic maps have appeared to date. New names have been applied to surface features.

Table III.2  
**CHEMICAL COMPOSITION OF VENUSIAN ROCKS (WEIGHT, %)**  
**MEASURED BY VENERA 13 AND VENERA 14**

Element (oxide)	Venera 13	Venera 14
MgO	11.4 ± 6.2	8.1 ± 3.3
Al <sub>2</sub> O <sub>3</sub>	15.8 ± 3.0	17.9 ± 2.6
SiO <sub>2</sub>	45.1 ± 3.0	48.7 ± 3.6
K <sub>2</sub> O	4.0 ± 0.63	0.2 ± 0.07
CaO	7.1 ± 0.96	10.3 ± 1.2
TiO <sub>2</sub>	1.59 ± 0.45	1.25 ± 0.41
MnO	0.2 ± 0.1	0.16 ± 0.08
FeO	9.3 ± 2.2	8.8 ± 1.8
SO <sub>3</sub>	1.62 ± 1.0	0.88 ± 0.77
Cl	0.3	0.4
Σ	< 96.11	< 96.29

Source: Surkov et al., 1983, p. 1.

An informal agreement exists that NASA Headquarters and the Venus Radar Mapper Project at the Jet Propulsion Laboratory (JPL) have a set of Soviet images to be used for planning purposes. It is anticipated that the NASA Regional Planetary Imaging Facilities will eventually receive all these informally released materials. Copies of pre-print papers have been distributed (Alexandrov, [1986]; Barsukov et al., 1984a-b, 1985; Geotimes, 1984; Kotelnikov et al. [no date]; Mouginis-Mark, 1985; National Geographic, 1985; Odyssey, 1984; Planetary Report, 1985; Science News, 1983; Sky and Telescope, 1984, 1985; Soviet Union, 1984).

## 2. Primitive Bodies

By mid 1986, the Soviets should have completed two excellent and very comprehensive flyby missions to Comet Halley, and they plan to have imaging of Halley from Salyut. During this period, the United States will have obtained good UV sensing of Halley (Pioneer, Venus Orbiter, ASTRO, and a Spartan) plus an exciting (but certainly less comprehensive) flyby of Comet Giacobini-Zinner (a true first with ISEE-3, renamed the International Cometary Explorer). In the minds of many, the Soviets (and the Europeans) will be well ahead in this area, especially if they succeed in obtaining images of the Halley nucleus. (The US is far along in the planning of an enormously important comet rendezvous mission, that could provide greatly enhanced cometary science, but this mission is designed to provide perihelion data in the 1997 time period.)

If the Galileo spacecraft is able to encounter Amphitrite in December 1986, then the United States will certainly be far ahead with asteroid exploration, at least until Vesta (see below).

## 3. Mars

Although the science return from the US Mariner Mars and Viking missions greatly exceeds the very limited return from the Soviet Mars program, it is ironic that the Soviet missions have been able to dominate in one area, involving the analysis of the Martian magnetosphere. Only the first US flyby (Mariner 4) carried a magnetometer, and the encounter was so far upstream that no conclusive planetary data could be obtained. Although many comprehensive US spacecraft returned to Mars (Mariners 6, 7, 8, 9, and

Viking 1, 2), the payloads never included any plasma physics instrumentation at all. Thus, when the Soviet included magnetometers and plasma probes on their missions, they were able to do first order discovery science.

#### **4. Outer Planets**

Although Soviet scientists have provided significant theoretical insights related to outer planet phenomena, this statement could also be made about European and Japanese scientists. In short, there really is no organized Soviet outer planets program, and the present US program of Pioneer 10, 11, Voyager 1, 2, and Galileo is completely dominant.

### **D. EXTRAPOLATION (KNOWN SOVIET PLANS)**

#### **1. Venus--The 1992 Vesta Mission**

The Soviet Union and France are planning a bold new mission to Venus and the main belt asteroids for the mid-1990 time period. Each launch in the 1992 Vesta Mission will include several Soviet spacecraft targeted to Venus and a French asteroid/comet flyby spacecraft. The Venus portion of the mission will include an atmospheric probe (presumably similar to the Venus Atmospheric Probe Mission proposed by the NASA Solar System Exploration Committee), a lander and a long duration "floating vehicle" that could operate in the upper atmosphere of Venus for a month or more. Some Soviets have used the word "kite" in description, and the term could refer to a solar sail, but the concept of an atmospheric airplane for Venus has also been discussed (Linkin et al., 1982). An alternate concept for this floating station involves a pair of balloons linked by a long tether.

#### **2. Primitive Bodies**

##### **a. Rendezvous With Phobos**

Rendezvous with Phobos (April 1988 launch--rendezvous phase in 1989); possible Deimos rendezvous using Phobos 2 if the initial spacecraft does well; first of post-Venera "three-year" spacecraft. The Phobos study will use instruments on the Orbiter (O), and on a descent platform (DP) or "hopper." The Phobos-related instruments are as follows:

- Laser Mass Spectrometer (O)
- Secondary Emission (ion beam) Mass Spectrometer (O)
- IR Spectrometer (O)
- Radar Altimeter (O)
- TV Camera (O)
- Scintillation Gamma Ray Spectrometer (O)
- Neutron Detectors (O)
- X-ray Fluorescence (DP)
- Penetrometer (DP)
- Magnetometer (DP).

A drawing of the Phobos spacecraft is shown in Figure III.3, and the orbit phases are indicated in Figure III.4, along with relevant Mars 2, 3 measurements related to the planet-solar wind interaction.

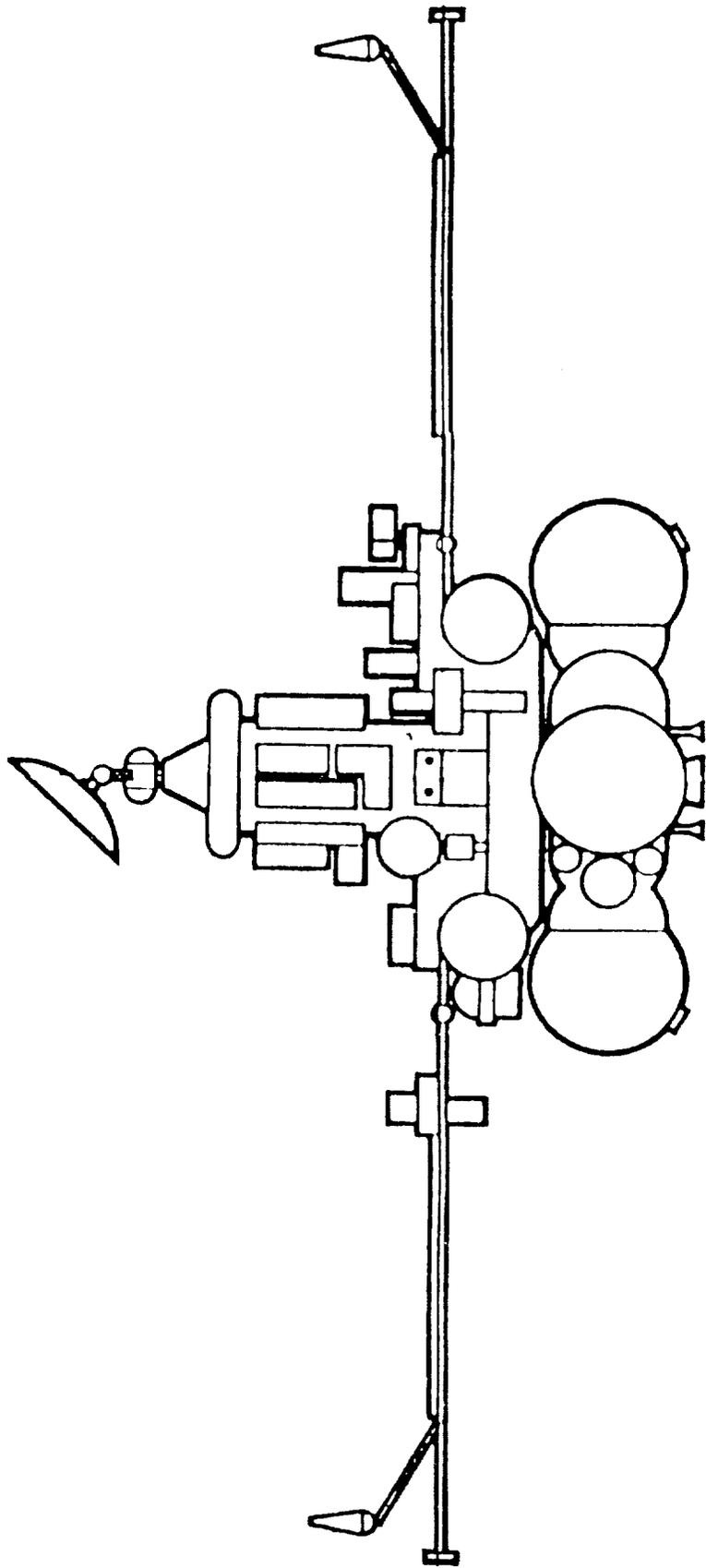
b. The 1992 Vesta Mission/Asteroid-Comet Phase

The main Soviet spacecraft could continue to earth-crossing asteroids after the Venus flyby, and the French spacecraft would be targeted (using one or more gravity assists) to the main asteroid belt for flybys of several large asteroids such as Vesta (this mission would address several key objectives of the Mainbelt Asteroid Multiple Orbiter/Flyby Mission proposed by NASA's Solar System Exploration Committee). The joint Soviet-French mission includes a comprehensive science payload with a television camera, IR spectrometer and radiometer, photopolarimeter, magnetometer, accelerometer, and dust detector. A descent module or a penetrator is also being considered. Another possibility involves comet flybys (Comets Kopff and Gehrels) for one of the dual launch spacecraft.

**3. Mars**

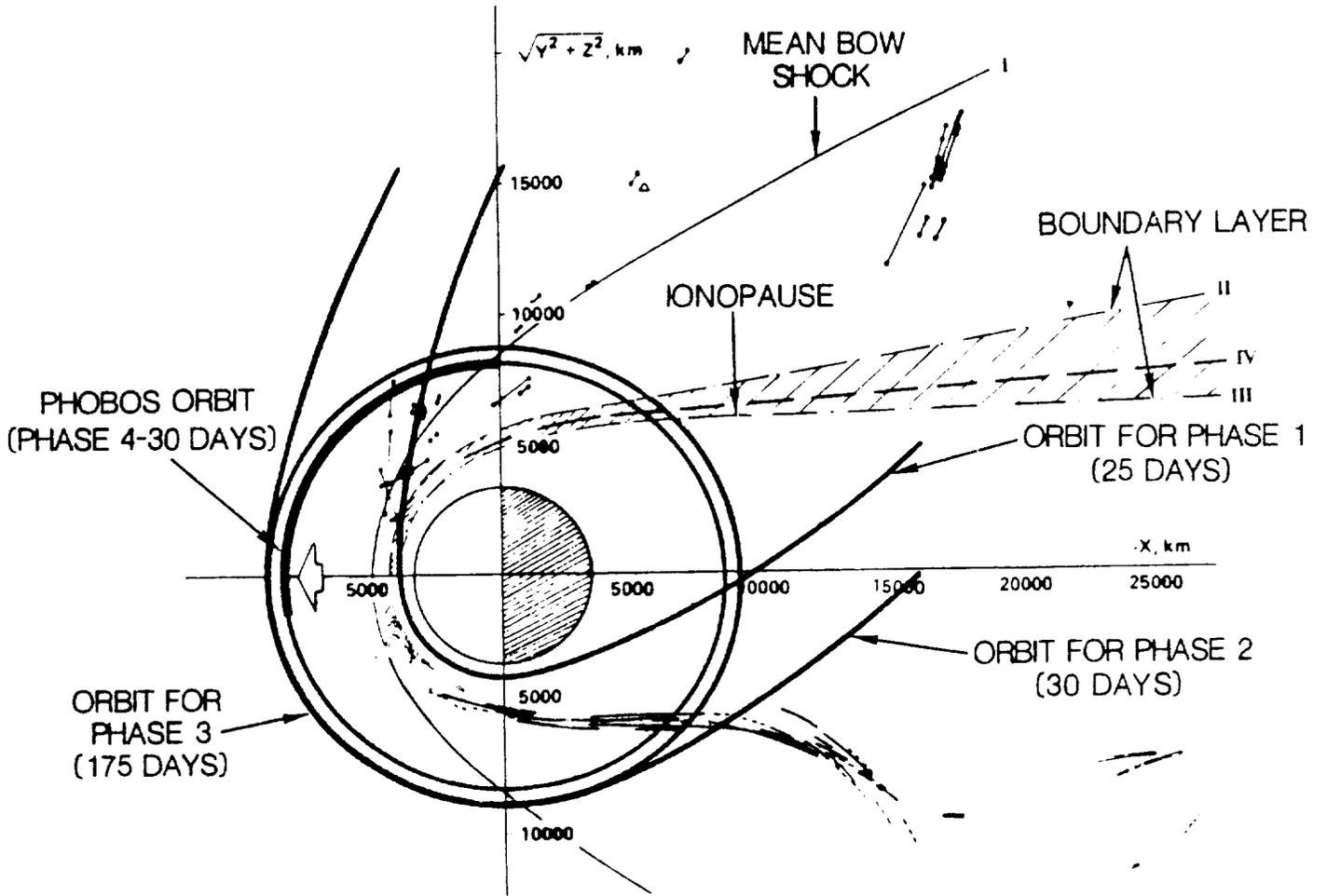
The Phobos project has a "Mars phase" which includes study of aeronomy, solar wind interaction, the Martian magnetosphere and magnetic tail, etc. Unless the Soviets use more powerful boosters or gravity assists, these Mars missions (which take advantage of a special low energy trajectory for 1988) will probably represent a singularity in the Soviet program. The "Mars phase" instruments include:

Figure III.3  
DRAWING OF THE PHOBOS SPACECRAFT



**PROJECT PHOBOS**

Figure III.4  
 PHOBOS ORBIT PHASES



- Scintillation Gamma Spectrometer (0.1-10 MeV)
- Solar Wind Ion, Charge Composition (50 eV/q-30 keV/q)
- Scanning Plasma Analyzer (0.5 eV/q-30 keV/q)
- Low Energy Ions and Electrons (0.5-1000 eV)
- Plasma Wave Investigation (1 to 100,000 Hz)
- Langmuir Probe
- Magnetometer (DC to 80 Hz)
- Spectrophotometer (250 nm - 4  $\mu$ m)
- Topside Sounder (0.18-2.81 MHz)
- Radio Science

In Soviet discussions with the ESA, it has been agreed that these Mars phase instruments, plus an additional solar instrument package, could be used to support the NASA-ESA Ulysses mission by providing in-ecliptic monitoring support during the solar polar passages. Some of these solar physics instruments could benefit the Mars study, and it is of interest to list these also:

- Solar Wind Proton-Alpha Spectrometer (0.15-6 keV/q)
- Solar Cosmic Rays (20 keV [electrons] to 3.4 MeV [H<sup>+</sup>])
- Solar Cosmic Rays (0.9 MeV [electrons] to 75 MeV/Nucleon)
- Solar X-rays/Coronagraph (0.5-6 nm; 17-30 nm; 400 - 600 nm)
- X-ray/UV (0.3 nm-130 nm)
- Gamma Ray Bursts (3 keV-10 MeV)
- Solar Oscillations (under development)

The Phobos mission is exceptional in many ways, and one noteworthy development involves the very strong participation of Western European scientists. Several new groups from France and Austria are involved, and the Phobos payload also includes hardware contributions from West Germany (FRG), Finland, Sweden, and the ESA.

#### 4. Moon

The Soviet plans for a lunar polar orbiter mission appear to be active again at this time. The project has been described as the "Lunar Polar Satellite--89-90" with a thirteen instrument (- 300 Kg) payload, as follows:

- TV Camera
- Gamma Ray Spectrometer (Ge)
- X-ray Spectrometer
- Neutron Detectors
- Spectrophotometer
- IR Spectrometer
- Altimeter
- Charged Particle Spectrometer (Superthermals?)
- Plasma Probe
- Micrometeorite Analyzer
- Magnetometer
- Electron Spectrometer (reflected electrons)
- Scintillation Gamma Spectrometer

It appears that all of these instruments will be developed by the Soviet Union and Eastern Bloc countries.

#### 5. Outer Planets

We know of no plans for Soviet outer planets missions. It is likely that these are ruled out by booster, tracking, and spacecraft lifetime restrictions.

### E. EXPECTATIONS FOR FUTURE ACHIEVEMENTS

- Further use of the new three-year Soviet spacecraft to explore inner solar system objects. It is a bit difficult to predict the specific missions since the Soviet planetary program uses existing spacecraft (Venera, and now Phobos class), and the missions can be put together on very short time scales. It is said that the Venera 15, 16 mission was only started after the US VOIR mission was canceled (1982). Phobos gives another measure of the rapid development; the final payload was completely determined in the March-April 1985 time period, instrument deliveries are due in the summer and fall of 1986, and the launches will occur in the spring of 1988. With this flexibility, the Soviet planetary program (which will probably, in a very general sense, follow that outlined by NASA's Solar System Exploration Committee) can await results of earlier missions or results of new instrument development programs.

- Continued use of planetary space science to offer unique opportunities for Western European scientists, at least for the missions or parts of missions that are managed and designed at the Space Research Institute (Institut kosmicheskikh issledovaniy). (This includes VEGA, Phobos, and Vesta; it appears that those missions focused on surfaces, and interiors, e.g., Venera 15, 16 and Lunar Polar Satellite; and have science payloads and investigation teams drawn from the Soviet Union and the Eastern Bloc.)
- Increased cooperation with NASA and US scientists, if the US-Soviet agreement is renewed. Several invitations to provide US hardware for Soviet missions have already been extended, and it is likely that these opportunities could work out with an agreement. Of course, the United States would have to find a way to accommodate Soviet scientists also; the lack of reciprocity with Europe has certainly been noted by individual scientists in the Soviet Union.
- Manned Mars Mission? Although many commentators have noted that the long-duration Salyut missions could naturally be connected with plans for manned missions to Mars (especially Apollo-11-type manned flyby missions), this possibility is strongly discounted in conversations with key Soviet scientists. Indeed, despite Phobos (which takes advantage of a unique launch opportunity), the long-standing Soviet lack of interest in Mars would seem to argue strongly against any Mars mission with a landing on the planet, but perhaps a landing on Phobos could be in the plan.

## **F. IMPACT ASSESSMENT**

It has been said that the US public perceives the space program as having three parts:

- manned missions,
- planetary missions, and
- everything else.

It is likely that the Soviet public could be described in the same way. The interest of the Soviet public in their planetary missions is very evident when one scans the frequent newspaper accounts that describe the launches, the spacecraft status, the cruise maneuvers, the progress in approaching the planetary object, etc. This unprecedented public interest is probably one of the important motivations for the Soviet planetary program, and it must generate a concept of technological and scientific competence throughout their society. The program also generates the same result abroad, and in this sense it seems that the Soviet planetary program is increasingly related to foreign policy, with a focus on the science community in Western Europe.

The impact of the new Soviet programs on the US lunar and planetary effort could be devastating. Several years ago, the NASA Solar System Exploration Committee formulated a mission plan designed to provide first-order science in a tightly constrained budgetary environment. The individual SSEC missions necessarily addressed narrowly focused objectives, and this is especially true for the Planetary Observer line that included a Mars geoscience/climatology orbiter, a Lunar geoscience orbiter, a Venus atmosphere probe, a near-Earth asteroid rendezvous mission, a Mars aeronomy orbiter, etc. The Soviet scientists are apparently able to go ahead with considerably more comprehensive missions to the same inner solar system targets; moreover, because of the continuing fiscal problems in the United States, some of the Soviet missions will be finished before we are even started.

**Table III.3**  
**KEY SOVIET RESEARCHERS AND INSTITUTIONS:**  
**LUNAR AND PLANETARY SPACE RESEARCH**

DIRECTION

R. Z. Sagdeyev	Director, Space Research Institute, Moscow (Institut kosmicheskikh issledovaniy/IKI)
V. L. Barsukov	Director, (Vernadskiy) Institute of Geochemistry and Analytical Chemistry, Moscow (Institut geokhimii i analiticheskoy khimii imeni V. I. Vernadskogo)
V. A. Kotel'nikov	Interkosmos Council for Scientific Space Research
G. S. Balayan	Interkosmos Council for Scientific Space Research

PLANETARY PLASMA THEORY

R. Z. Sagdeyev	Director, Space Research Institute, Moscow (Institut kosmicheskikh issledovaniy/IKI)
A. A. Galeev	Space Research Institute, Moscow
L. M. Zelenyy	Space Research Institute, Moscow

PLANETARY PLASMA MEASUREMENTS

K. I. Gringauz (plasma probe measurements)	Space Research Institute, Moscow
Sh. Sh. Dolginov (magnetometers)	Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation Institute, Troitsk (Institut zemnogo magnetizma, ionosfery i raspro- straneniya radiovoln/IZMIRAN)
S. I. Klimov (plasma wave measurements)	Space Research Institute, Moscow
O. L. Vaysberg (plasma probe measurements)	Space Research Institute, Moscow
T. Breus (plasma data analysis)	Space Research Institute, Moscow
I. M. Podgorniy (laboratory simulations)	Space Research Institute, Moscow

**Table III.3**

**KEY SOVIET RESEARCHERS AND INSTITUTIONS:  
LUNAR AND PLANETARY SPACE RESEARCH**

(continued)

PLANETARY REMOTE SENSING

V. A. Krasnopol'skiy (optical and IR spectroscopy)	Space Research Institute, Moscow
L. V. Ksanfomaliti (IR; also wave measurements, seismology)	Space Research Institute, Moscow
V. I. Moroz (optical spectrophotometer)	Space Research Institute, Moscow

PLANETARY ATMOSPHERES AND CLOUDS

V. G. Istomin (mass spectrometers)	Space Research Institute, Moscow
L. M. Mukin (gas chromatograph)	Space Research Institute, Moscow
M. Ya. Marov (nephelometer; atmospheric structure and dynamics)	Institute of Applied Mathematics (Institut prikladnoy matematiki)
Yu. A. Surkov (hydrometer; x-ray fluorescence)	(Vernadskiy) Institute of Geochemistry and Analytical Chemistry, Moscow

PLANETARY SURFACES, INTERIORS, etc.

V. L. Barsukov	Director, (Vernadskiy) Institute of Geochemistry and Analytical Chemistry, Moscow
Yu. A. Surkov	(Vernadskiy) Institute of Geochemistry and Analytical Chemistry, Moscow
A. T. Basilevsky	

**CHAPTER III: LUNAR AND PLANETARY SPACE RESEARCH:  
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## CHAPTER IV SPACE ASTRONOMY AND ASTROPHYSICS

### A. INTRODUCTION

The Soviet literature and known Soviet space activities provide ample indication that the Soviet Union has been devoting a large and somewhat systematic effort in the space exploration of the inner solar system, compared to space astronomy outside the solar system. It is clear that Soviet theoretical astrophysics enjoys an international reputation, compared to mediocre Soviet experimentation resulting from lack of modern devices and computers.

Soviet scientists have been very active in high energy astrophysics--both theoretical and experimental. Some of their more successful areas of experimental research have been:

- cosmic rays and gamma rays,
- gravitational radiation, and
- anti-matter research.

However, none of these areas have produced revolutionary new discoveries like:

- the 3K cosmic background radiation,
- quasars,
- pulsars,
- interstellar molecules,
- interstellar masers, and
- x-ray sources,

all of which were discovered by scientists in the West.

Soviet scientists are deeply aware of the fundamental importance of cosmic research. Aviation Week recently filled a page with three posed photographs of "a Highland Cosmic Ray Station at Zailyiskiy Alatau, 3400 meters above sea level for research

and experimentation on cosmic particles" (Aviation Week, 1985, p. 93), and the works of a number of Soviet space researchers have appeared in Western editions in recent years (see, Syunyayev, 1985; Zel'dovich, Ruzmaykin, and Sokolov, 1985).

The world in turn recognizes the quality of Soviet cosmological study: The International Astronomical Union, which meets once tri-annually, at its most recent meeting, in Patras, Greece, chose Academician Ya. B. Zel'dovich (Space Research Institute [Institut kosmicheskikh issledovaniy] and Institute of Applied Mathematics [Institut prikladnoy matematiki], USSR Academy of Sciences, Moscow) to present an "invited discourse" entitled "Modern Cosmology." (The other three were: a Briton on history; a Dutch astrophysicist on solar flares; and a US astronomer on the origin of the solar system).

Cosmology is the study of the universe as a whole. Historically, our cosmological ideas have been influenced in the profoundest degree by observation. It was the US astronomers Slipher and Hubble who discovered, using telescopic observations, the fact that the universe is expanding. For a long time, the United States had the largest telescope in the world, the five-meter Mt. Palomar Hale telescope. Now that honor goes to the Soviet Union's six-meter telescope. Cosmic microwave background radiation was discovered by US scientists. Now the Soviet Union has observed this radiation from space, while the corresponding (although much more sophisticated) US space experiment is still under construction.

However, the Soviet Union, which has a keen appreciation of the importance of space astrophysics in general, and cosmology in particular, and which, unlike any other nation on earth (save, until recently, the United States), has had very easy and frequent access to space but has done extraordinarily little in the way of cosmic space research. This will be discussed in detail below.

The international journal, Nature, published in Great Britain, is a meeting ground for all nations engaged in scientific research. A glance at a recent issue (13 June 1985) gives one a feeling for certain aspects of current astrophysical research and the Soviet role. Let us note first "EXOSAT Observations of a 2000-Second Intensity Dip in Seyfert Galaxy NGC 4151," by British astronomers (Whitehouse and Cruise, 1985) reporting important x-ray observations, using a European space satellite experiment. The observations support the notion that in the center of some (or all) galaxies, there is a ten-to-one-hundred-million-solar-mass black hole (neither the Soviet Union nor the United States

currently has a significant x-ray astronomy satellite in orbit). Next, we note "High-Precision Timing Observations of the Millisecond Pulsar PSR 1937+21," by US astronomers Davis et al. (1985) (and summarized, by a British astronomer on page 540 of the "News and Views" section). Discovery of pulsars won the British a Nobel prize, but the exploitation has been overwhelmingly American. The present observation is notable because ground-based radio observations are used to directly infer physical conditions when the universe was only  $10^{-4}$  seconds old. Finally, coming to the Soviet role, we find a letter, "A Model of Object Geminga as a Degenerate White Dwarf Orbiting Around a Black Hole" (Bisnovatyy-Kogan, 1985). The black hole referred to is only a few solar masses, not millions. The author is G. S. Bisnovatyy-Kogan of the Space Research Institute in Moscow. The "object Geminga" is a cosmic gamma-ray source, discovered by the European COS-B satellite. It has recently been identified as an x-ray source, and also as an optical object in the sky, in both cases by non-Soviet astronomers. Bisnovatyy-Kogan offers a theoretical model for accounting for the observations, particularly the observed one-minute periodicity and rapid change of period (doubling time only several hundred years). The model involves a degenerate dwarf star spewing material into a black hole. The two objects are in orbit around each other.

While these articles are only three from among the thousands published annually, they provide a not-inaccurate picture of the state of Soviet space astrophysics today: active current European observational experiments in orbit; a lull, to some extent, in US space activity, but vigorous ground-based activity; and little or nothing from the Soviets except interesting and useful theoretical interpretations and insights.

In this report, we examine Soviet "space astrophysics" research, "space" astrophysics being only one portion of observational astrophysics. How important a part it is depends on the wavelength of radiation that is under consideration. (Our discussion below is organized by wavelength: see Table IV.1.) For example, x-ray astronomy and ultraviolet astronomy cannot be carried out except via space research. For optical and radio astronomy, the opposite is the case: they can be done from the ground, and for the first 28 years of access to space, very little optical or radio-astronomical research has been conducted in space; other spectral regions demanded attention first. Now, however, with mature space technology, it is possible to do extremely valuable things from space, in both the optical and radio spectral ranges. The outstanding proof is surely the Space Telescope, due to be launched by NASA in 1986.

**Table IV.1**  
**WAVELENGTHS OR ENERGIES OF TYPES OF**  
**ELECTROMAGNETIC RADIATION**

Type of Radiation	Wavelength in Angstroms	Wavelength in Microns	Wavelength in cm	Energy in keV
Gamma Ray				124 - ∞
X-Ray	0.1 - 912			0.014 - 124
Ultraviolet	912 - 3000			
Visible	3000 - 7000	0.3 - 0.7		
Infrared		0.7 - 1000		
Radio			0.1 - infinity	

one Angstrom =  $10^{-8}$  cm

one Micron =  $10^{-4}$  cm

Energy in keV =  $12.4 / (\text{wavelength in Angstroms})$

In the radio part of the spectrum, what space offers is large antenna spacing. In Great Britain, Sir Martin Ryle won the Nobel Prize for his notion of "aperture synthesis," the use of small radio antennas in various locations to simulate a vastly larger telescope. The United States is currently constructing a large network of radio telescopes to exploit this British invention: the VLBA (very long baseline array) project. Even better results could be achieved if a space component were added: a moderate-sized antenna in space, moving relative to the network of antennas on earth. The proposed US ground-based effort is that of the US National Science Foundation (NSF). NASA is considering an experimental effort in space, proposed by Bernard Burke at the Massachusetts Institute of Technology (MIT).

What of the Soviets in these "most sophisticated" areas? There is no hint of a Soviet competitor to the optical space telescope. The Soviets have been very active in VLBI (very long baseline interferometry) and certainly consider space VLBI an important future area of research.

The space astrophysics research cannot be studied outside the context of astrophysics research in general, but in writing this report we must contend with the problem of astrophysics being a vast field. Our mandate is space, and if we were to cover astrophysics without bias, space would form only a small part, particularly on the Soviet side. Therefore, we have included ground-based research only to the degree that it is directly relevant to aspects of Soviet space research, or forms an important background for it.

An important element here is technology, in particular, detectors of electromagnetic radiation. An important interplay is involved, which has three elements: military detectors, ground-based astronomy detectors, and space-based astronomy detectors. It is easiest to understand this interplay by considering the history of detectors in the United States, where at least some of the needed information is freely available. The Soviet story is a matter of inference. In the United States, detection of optical radiation was almost exclusively by photographic means until after World War II, when astronomers began widespread use of photomultiplier tubes. These had the advantages, over photography, of sensitivity and linearity, both vitally important for astronomy. What they lacked was the ability to detect more than one pixel. The 1960's and 70's saw largely fruitless endeavors to extend photoelectric detection to include photography's advantage. Success was finally achieved in the late 1970's, with needs prescribed by the

Space Telescope. NASA's need for excellent detectors for the Space Telescope (and for the Galileo mission) led to the extensive development and implementation of the Bell Laboratories' new CCD (charged coupled device), which has as many as 800 x 800 pixels and is both quantum-efficient and linear. While it is known that the US military has spent vast sums on infrared detector development, there is no hint of such spending in the visible field. Yet it is hard to believe that high-quantum efficiency panoramic night vision is not of great interest and value to defense.

What of the future Soviet astrophysics research program? The Astron and Prognoz 9 missions described below suggest that the Soviets plan a substantially more active astrophysics program in the future than they have conducted in the past. At the COSPAR/IAU Symposium held in Rojen, Bulgaria, 18-23 July 1983, the Soviets described their future plans. The published proceedings (Bignami and Syunyaev, 1984), however, do not provide all of the information given verbally by the Soviets at the meeting. The information was gathered from participants by the secretary-treasurer of the American Physical Society (APS) and published in the APS Astrophysics Newsletter of September 1983. As this reference is not available in libraries, and the information is of importance for the present report, we reproduce the relevant material verbatim in Tables IV.2 and IV.3 (it should be kept in mind that the following is only a partial summary):

**Table IV.2**  
**OPERATIONAL SOVIET SPACE MISSIONS**

PROGNOZ-9 (USSR)	<ul style="list-style-type: none"> <li>● 10 keV-6 MeV Burst Detectors (with France)</li> <li>● Microwave Background Anisotropy Experiment</li> </ul>
ASTRON (USSR)	<ul style="list-style-type: none"> <li>● 1100 Å-3600 Å UV Telescope (80 cm--31.5 in--primary mirror) (with France)</li> <li>● 2-25keV Proportional Counters--1780 cm<sup>2</sup></li> </ul>

**Table IV.3**  
**PLANNED SOVIET SPACE MISSIONS**

	<u>Launch</u>	<u>Instruments</u>
GAMMA-1 (USSR)	1984-85	<ul style="list-style-type: none"> <li>● 50 MeV-5 GeV Spark Chamber with coded mask (with France)</li> <li>● 0.2-2 MeV Scintillation Detector--150 cm<sup>2</sup></li> <li>● 2-20 keV Proportional Counters (600 cm<sup>2</sup> total) with coded mask for x-ray bursters, transients, and pulsars</li> </ul>
X-RAY OBSERVATORY (USSR)	1985	<ul style="list-style-type: none"> <li>● 2-80 keV Gas Scintillation Proportional Counter--300 cm<sup>2</sup> (with ESA)</li> <li>● 2-30 keV Proportional Counter (1000 cm<sup>2</sup>) with coded mask (with Holland)</li> <li>● 15-200 keV Scintillation Detectors--800 cm<sup>2</sup> (with Germany)</li> <li>● 20-800 keV Scintillation Detectors (1000 cm<sup>2</sup>) with coded mask (USSR)</li> <li>● 0.02-2 MeV Detector--150 cm<sup>2</sup> (USSR)</li> </ul>
SIGMA (USSR)	1987	<ul style="list-style-type: none"> <li>● 20-700 keV experiment using position-sensitive scintillation detector and coded mask--2600 cm<sup>2</sup></li> <li>● 3-150 keV position sensitive Xenon proportional counter with coded mask--600 cm<sup>2</sup></li> <li>● 3 keV-10MeV x-ray and gamma-ray burst experiment (3 detectors)</li> </ul>
SUBMILLIMETER TELESCOPE		<ul style="list-style-type: none"> <li>● 100 micron-2 mm; 1-meter diameter mirror (US <math>\Delta\lambda/\lambda \sim 0.1</math> and 0.001 spectrometers)</li> </ul>

Finally, it should be noted that the present report does not include any examination of Soviet work in laboratory astrophysics. Laboratory astrophysics is a step-child of fundamental long-term importance that has not been well treated in the United States, and to which the Soviets, in fact, have contributed very significantly. The subject is probably worth a separate investigation.

## **B. GAMMA-RAY ASTRONOMY**

### **1. Introduction**

World War II produced intense development of nuclear physics. The characteristic energy of the atomic nucleus is that of gamma rays. Following the war, US scientists (and others) realized the potential importance of gamma-ray astronomy. After all, the stars were known to be powered by nuclear reactions, and supernova explosions would presumably release vast quantities of radioactive species. Calculations of the expected intensity of gamma-ray emission were uncertain but evidently not too discouraging, as a vigorous and continuing balloon astronomy program resulted. For a very long time, the results of this program and of several satellite-borne experiments were few.

This situation changed in the 1970's, when OSO (orbiting solar observatory), Apollo, SAS (small astronomical satellite), and balloon-borne activities began delivering real results.

Gamma-ray astronomy can be subdivided in a number of ways: point objects, versus diffuse background; low-energy (really, hard x-rays), medium energy ( $\sim$  MeV, the region of nuclear line emission), and high energy ( $\sim$  100 MeV, and higher); or on the basis of time-behavior--gamma-ray bursts, and all the rest.

### **2. Gamma-Ray Bursts**

Gamma-ray bursts occupy a special place in our report, because of their relationship to defense, and because of the magnitude of the Soviet contribution.

The Soviets have made what could perhaps be called a major discovery in the paper, "Observations of a Flaring X-Ray Pulsar in Dorado," by E. P. Mazets et al. (1979b), reporting a result from Venera 11 and 12. This important work, which we will describe

shortly, can only be appreciated in the context of the history of gamma-ray bursts. The initial, very important, discovery of gamma-ray bursts was American, and was fortuitous. Los Alamos scientists flew gamma-ray detectors (on Vela satellites) that incorporated high time-resolution, with the aim of detecting surreptitious Soviet (or other) nuclear bomb tests in or above the atmosphere. The use of multiple satellites allowed approximate locations of the source of an explosion through study of the pulse arrival times at the various satellites. To everyone's intense surprise, "nuclear explosions" were detected in considerable numbers, in directions away from the earth.

This discovery led to many theories as to the source of the bursts. These theories ranged from "relativistic dust grains striking solar photons," to "comets falling onto neutron stars." The mystery was heightened by the fact that bursts apparently occurred randomly over the sky; large telescopes revealed nothing at the sky location of any burst; and bursts did not recur at the same spot in the sky. The mystery has not been resolved yet today.

These "gamma-ray" bursts are predominantly low-energy, that is, they could equally well be called "hard x-ray bursts." Some confusion is also introduced into the subject by the existence of another very interesting class of objects called "x-ray bursters"; we will discuss the Soviet contribution in this area elsewhere.

The paper by Mazets et al. (1979b) to which we have just referred, concerns what was, at least initially, believed to be a "traditional" gamma-ray burst on 5 March 1979. But Soviet analysis showed that time periodicity ( $8.1 \pm 0.1s$ ) was present in the gamma-ray intensity. This was the first hint of any such effect in gamma-ray bursts, and was a major discovery. It strongly suggested, in a general way, that the object of origin was a neutron star. By inference, one would then suppose that all gamma-ray bursts were associated with neutron stars, perhaps the results of "star-quakes." What has complicated the matter, however, is the fact that unlike the case for most gamma-ray bursts, large telescopes do reveal an object at the burst location, and a remarkable one indeed: a supernova remnant in another galaxy!

Does the 5 March 1979 event really originate in our neighbor galaxy, called the Large Magellanic Cloud (LMC), or does it originate in a nearby neutron star that happens, by very bad luck, to lie directly on our line of sight to the LMC supernova remnant? No one knows. If it does originate in the LMC, the gamma-burst energy is considerably greater than that of "normal" bursts (assuming that these originate in our own galaxy).

It is important to realize that the Soviets were able to make a major discovery out of a field that had been created, accidentally, by US efforts. Because the Soviet contribution to the study of gamma-ray bursts is so much more significant than their work in any other area of observational astrophysics, we will document it with particular care.

We begin with the Franco-Soviet Signe (Sneg) instrument, which is described by Niel et al. (1976), and which began operation aboard "the automatic space station, Prognoz 6" on 16 September 1977. First results (detection of three gamma-ray bursts) are reported by I. V. Estulin et al. (1978). Accurate location of gamma-ray bursts requires detection by more than one satellite (in fact, the more the better), and in the paper by Kuznetsov et al. (1979), we find the Franco-Soviet group reporting "Site Constraints for Sources of Gamma-Ray Bursts Recorded by the Prognoz 6 and Sneg 3 Satellites," and in the work by Estulin et al. (1979), we find US involvement with the coordination of Prognoz 6 and Helios (US) data.

Soviet interplanetary experiments resulted in the important "5 March 1979" discovery. The reason for wanting gamma-ray burst experiments on planetary missions has nothing (at least scientifically) to do with the planets--it is just that one wants a long triangulation baseline to test, say, whether the bursts originate within our own solar system (the "relativistic dust grain" theory). They do not. Planetary missions are also possibly useful for checking as to whether another nation is secretly testing nuclear weapons, using the planet as cover.

The first results of the Franco-Soviet Venera 11 and 12 experiments are presented by Mazets et al. (1979a), who report observations of 21 bursts. Further results are given by Mazets et al. (1979c), while additional results are reported by Zenchenko et al. (1979).

We have already discussed the remarkable 5 March 1979 event, which was also reported by Barat et al. (1979) and by Mazets et al. (1979d). Results of observations by other satellites are reported by Vedrenne et al. (1979), while analysis of certain important details is given by Barat et al. (1983).

An important aspect of the 5 March 1979 object not yet mentioned was reported by Golenetskiy et al. (1979), namely the discovery of "weak recurrent bursts" from the same object, with reports of further activity from Golenetskiy et al. (1982).

Also extremely interesting and important is the discovery (Mazets et al., 1979e) of recurrent bursts (on 24, 25, and 27 March 1979) at a location near the plane of our own galaxy. The relationship of this to the object that underlies the 5 March 1979 event, and/or to "traditional" gamma-ray bursts, remains speculative.

For the record, additional Venera 11, 12 gamma-ray burst papers include those by Chevalier et al. (1981); Estulin et al. (1981); D'yachkov and Zenchenko (1981); and Barat et al. (1984).

The Soviet and Franco-Soviet gamma-ray burst activity continued on Venera 13 and 14. The "Konus" experiment is described in a paper by 18 Soviet authors (Andreyev et al. 1983), while the superior "Sneg-2M3" instrument and results are described by four Soviet and four French authors in the paper by Estulin et al. (1983).

An American-French-Soviet paper in the US Astrophysical Journal (Cline et al., 1984) describes an important recent discovery: two optical flash events associated with a gamma-ray burst location.

We have not described the various US gamma-ray burst experiments, but unlike the situation in virtually every other area of astrophysics, these are only "comparable to" the (Franco-)Soviet effort--if that.

Soviet efforts at interpretation and study of gamma-ray bursts are thin. Nine Soviet authors (Mazets et al., 1979f) from the Ioffe Institute (Fiziko-tekhnicheskii institut imeni A. V. Ioffe), studying the "Distribution of Cosmic Gamma-Ray Burst Sources Over the Celestial Sphere," report that the sources are concentrated in the galactic plane, but Western experts believe that this effect is not real--it is due to what

are called "selection effects," a common bug-bear in astronomy. Another method of systematic study of bursts is the counting of "how many of them are how bright." Analysis can provide clues to the origin of the bursts. We find two papers on this subject, a Soviet paper, "Intensity Distribution of Cosmic-Ray Bursts" (Mazets et al., 1978), by five Ioffe authors, and a paper by five French (and no Soviet) authors (Barat et al., 1982), which analyzes "Franco-Soviet SIGNE experiments" and does not reference the earlier paper (which claimed to deduce a galactic origin for the bursts).

An odd paper by A. V. Kuznetsov (1982), analyzes the properties of bursts and concludes, surely quite incorrectly, that they are heliospheric in origin. There does not seem to be any "orthodoxy" in Soviet astronomy papers. We reviewed one paper by a Soviet author (Pustil'nik, 1979) that is supportive of the minority view of the nature of the red-shifts of quasars (i.e., that the red-shifts are not cosmological in origin).

A recent gamma-burst "analysis" paper (Barat et al., 1984) of some interest was published in the US Astrophysical Journal by seven French authors and Soviet researchers, including Estulin (whose recent death was noted) and Zenchenko (Space Research Institute, Moscow). In this paper, the rise and decay time characteristics and the energy spectra of 20 short, single-peaked gamma-ray bursts detected by the Franco-Soviet Signe instruments are analyzed in detail.

Finally, we come to the important question of lines in the spectra of gamma-ray bursts. In 1978, a West German group reported evidence for line emission at 58 keV in the spectrum of the x-ray binary Hercules X-1, attributing it to "cyclotron emission," which implies the (not-surprising) presence of a very intense magnetic field. Also, US balloon-borne experiments have provided evidence for electron-positron annihilation radiation from the center of our own galaxy (the effect of a black hole, somehow?), which is characterized by emission at 511 keV. Then, Mazets et al. (1980) reported that:

The gamma-ray burst spectra observed in the Cone experiment on the Venera 11 and Venera 12 spacecraft display lines, suggesting that the burst sources involve neutron stars with a strong magnetic field. The 511-keV annihilation line is gravitationally redshifted, and is recorded as an emission line in the 400-450 keV energy range. Furthermore, absorption of radiation in the sources at the cyclotron frequency in a field of order  $5 \times 10^{12}$  Gauss sometimes produces a line of 30-60 keV energy.

The data that are presented by Mazets and his colleagues look very impressive indeed, and if correct, this represents a powerful clue to the origin of gamma-ray bursts. However, scientists at Los Alamos National Laboratory argue that the lines may well be entirely spurious, an effect of imperfection in instrument calibration.

### **3. The Soviet Gamma-Ray Astronomy Program--Overall**

Let us review the over-all Soviet gamma-ray astronomy program, describing its technology and observations--both point sources on the sky, and general diffuse cosmic emission.

Venera 5 and 6 ultraviolet detectors were protected by geiger counters against gamma rays. The ultraviolet experiment did not produce useable results, so the "noise" (gamma rays) was analyzed and published by Dement'yeva (1971). Early gamma-ray results from balloon flights and Salyut 1 are given in a paper by Iyudin and Ozerov (1975).

The technology of gamma-ray detection is unusually well-documented in the Soviet space astronomy program. For example, note the sequence of titles: "Calculation of the Characteristics of a Gamma-Ray Telescope by the Monte Carlo Method" (Gun'ko and Dmitriyev 1975); "Determination of Orientation of the Axis of a Gamma-Ray Telescope on Board an Earth Satellite" (Gur'yan, Mazets, and Sokolov, 1976); "Angular Resolution of Coded Aperture Gamma-Ray Telescope" (Kotov et al., 1984). All of this technology is standard; indeed, break-throughs are hardly to be expected in this area of technology. All of the above papers are purely Soviet; an example of French-Soviet technical cooperation in gamma-ray instrumentation testing (using Deutsches Elektronen-Synchrotron Laboratory, DESY, in Hamburg) is given in the work by Akimov et al. (1977).

In studying the history of a nation's gamma-ray astronomy program, it is important to be aware of the fact that in many respects balloon flights are actually superior to satellite flights. The reasons have to do with time-variability of cosmic-ray particle background (against which one must attempt to find the gamma-rays) and spacecraft "activation" (i.e., being made radioactive) by the Van Allen belts. Politically, however, satellite flights have certain advantages. All of this can lead to a peculiar, expensive, and somewhat wasteful program.

The Soviet satellite program seems to begin with Kosmos 135 (Konstantinov et al., 1970) in the 0.4 to 2.5 MeV energy range, and Kosmos 208 (Bratolyubova-Tsulukidze, 1970) at high energies ( $>50$ MeV). Additional observations of diffuse gamma-rays, in the energy range of 30 keV to 4.1 MeV, were provided by Kosmos 461 (Golenetskiy et al., 1974, describes the calibration; while Mazets et al., 1976, give the results).

The Meteor satellite, launched by the Soviet Union into a sun-synchronous orbit on 29 June 1977, carried an instrument for recording gamma-ray bursts which provided spectral data on the bright Crab Nebular x- and gamma-ray source. (This was really a hard x-ray experiment.) Gamma-rays above 100 MeV from the Seyfert Galaxy NGC 4151 were detected, using instruments aboard Kosmos 264 (Gal'per and Luchkov, 1979). This well-known galaxy has a very active nucleus, perhaps a black hole.

Three papers describe Kosmos 856 and Kosmos 914 observations of the diffuse gamma-ray background in the range 100 to 4000 MeV. The instrument description appears in the paper by Blokhintsev et al. (1982), while the data are presented by Nagornikh (1982) and Kalinkin and Nagornykh (1982). This work represents a useful contribution to a subject that was being intensely investigated in the West.

We emphasized above that balloon work remains a valuable approach, and evidence of Soviet appreciation of this fact appears in work by Iyudin et al. (1984 a, b). These papers describe the Natalya 1 gamma-ray telescope, a joint Indo-Soviet project. Two flights are reported: on 20 August 1979 from the Soviet Union, and on 6 November 1980 from India. The different latitudes of launch represent a virtue, as data can be affected by the terrestrial magnetic field. The first paper presents results on the diffuse background ( $>5$ MeV). This paper has only Soviet authors (from the Moscow Engineering Physics Institute [Moskovskiy inzhenerno fizicheskiy institut] and the Lebedev Physics Institute [Fizicheskiy institut imeni P. N. Lebedeva] in Moscow). The second paper, which adds four Indian authors (TATA Institute), reports observation of the Crab Nebula from five to 100 MeV. Both of these papers represent useful contributions.

Notable in this review is the absence of work on the very difficult subject of nuclear gamma-ray line emission. Our guess is that the Soviets find the subject too challenging. Soviet theoretical commentary on this subject includes the paper, "A Two-

Temperature Accretion Disk around a Massive Black Hole, and the Gamma-Ray Lines of the Centaurus A Nucleus," by A. S. Zentsova (1983), however, the analysis is of US observations.

We commenced our review of Soviet gamma-ray astronomy with the important subject of gamma-ray bursts, and followed that with an historical review, in which we omitted any mention of Soviet observations of a certain celestial object which in recent months has become a center of world-wide scientific interest, Cygnus X-3. We conclude with a discussion of this remarkable object.

#### **4. Cygnus X-3**

The name Cyg X-3 designates the third-brightest x-ray source in the constellation Cygnus. This source is a binary star, and the current interest originates in apparent detection, in underground proton-decay experiments, of elementary-particle events of a kind totally unexpected, and of unknown origin, but bearing the 4.8 hour period of Cygnus X-3. Speculation includes the notion that these are "strange lumps" (mesons are quark-antiquark pairs; hadrons [e.g., protons] are tri-quarks; "strange lumps" are predicted larger agglomerations of [strange] quarks).

Gamma rays were reported from Cyg X-3 in 1975 by the Soviets (Gal'per et al., 1975), and in 1977 by the users of the US SAD-2 satellite (Astrophysical Journal, 212 1977 , L63). Soviet balloon (40 MeV) and ground-based ( $2 \times 10^{12}$  eV) observations are reported in "Variability of Gamma Rays from Cygnus X-3" (Vladimirskiy et al. 1975) by nine Soviet authors from the Crimean Astrophysical Observatory and the Moscow Engineering Physics Institute, while balloon flights in 1972 and 1974 resulted in the paper, "Periodic Gamma-Rays from the Discrete Source Cygnus X-3" (Gal'per et al., 1976), by scientists at the Moscow Engineering Physics Institute. More recently, we note "On the Periodic Gamma-Ray Emission of Cygnus X-3" (Gal'per and Luchkov, 1984), an interesting and intelligent analysis and reconciliation of discrepancies among all gamma-ray measurements of Cygnus X-3.

In conclusion, we find that the Soviets have made a very significant contribution to the study of the enigmatic object Cyg X-3; have carried out a "routine" general gamma-ray astronomy program; and have contributed in a fundamental way to the study of gamma-ray bursts.

The United States leads the Soviet Union in gamma-ray astronomy, but not by much. The US "Gamma Ray Observatory (GRO)," now being prepared for launch, is considerably more sophisticated than the Soviet GAMMA-1, also now being prepared for launch. The US lead in the study of nuclear line emission is very great. The main Soviet emphasis is gamma-ray burst detection, which is technologically identical to nuclear-bomb-detonation detection; this may provide the underlying Soviet motive.

The Soviet Union could explode nuclear weapons behind the Moon, or any of the planets, and escape detection, unless the United States had gamma-ray burst detectors appropriately placed in space. They could, in principle, carry out (at very high cost) a systematic testing program of which we would remain in total ignorance.

### C. COSMIC RAYS

"Cosmic Rays" is an extremely broad term, used to refer to any high-energy cosmic particles other than photons (that is, the term includes, among other types of particles, protons and electrons). And these particles may have any cosmic origin--terrestrial, planetary, solar, galactic, or even extragalactic.

This section concerns only galactic cosmic rays (although often the same experiment will respond also to cosmic rays of more local origin). The source of galactic cosmic rays is unknown, but may be neutron stars distributed through the galaxy; a galactic center black hole; supernovae; slow acceleration in the interstellar medium; or some, or even all, of the above.

Depending on energy, cosmic rays may be studied from Earth, from balloons, or from space. Earth-bound study has a long and voluminous history, which we shall not discuss here. The earliest Soviet space cosmic-ray paper we find is "Measurement of Soft Radiation in the Equatorial Region by the Satellite Kosmos-4," by Savenko et al. (1964), followed by half a dozen other papers (on Kosmos 7, 17, 19, 25) from the 1960's. The Soviets missed discovery of the Van Allen belts, terrestrial "cosmic rays."

Cosmic ray electrons were measured on Kosmos 225, 264, 490, and 900, as well as on Prognoz 3 (Nikolayeva and Pisarenko, 1979).

Spacecraft flown as part of the Soviet planetary program carried cosmic ray detectors. We find a report on Mars 1 and Luna 4; a report on Luna 19 (Chuchkov et al., 1975); a report on Mars 7 electron studies (Alekseyev et., 1982); a report on Venera-9 and 10 (Alekseyev et al., 1976); and a report on Venera 11 and 12 (Vernov et al., 1979). There have been no Soviet missions to the outer planets, where US particle experiments have been very productive.

Papers that seem to offer more than just measurements are "Compatibility of Measurements of the 'Proton' Satellites, Data on the Sidereal-Diurnal Variation, and Different Theories of the Origin of Cosmic Rays" (Dorman, 1969), "Excess Cosmic Ray Emission" (Savenko, Sarayeva, and Shavrin, 1978), and "Periodicity of Galactic Cosmic-Ray Flux Variations and Solar Activity Parameters Near the Minimum of the Twentieth Cycle" by four authors (Gorchakov et al., 1984).

Even without being expert in this particular area, one gets a feeling that these papers describe a program that is not up to the opportunity. In making this assessment, one should keep in mind that, at a fundamental level, the Soviets "wrote the book" on cosmic rays: one of the most widely reported references is the work by Ginzburg and Syrovatskiy (1964).

In the area of general interpretation and theory, all we find is the very interesting paper, "Can the Ultra-high Energy Cosmic Rays Stem from the Galactic Center?" (Berezinskiy and Mikhaylov, 1984), which argues that ultra-high-energy cosmic rays cannot originate in the nucleus of our own galaxy.

Perhaps the most interesting aspect of all cosmic ray research, is the search for anti-matter. Discovery (which has not occurred and is not really expected) of even a single, say, anti-oxygen atom, would prove the existence of anti-worlds. What has been discovered is exciting enough: anti-protons, and in unexpected quantity! The discovery could have been that of the NASA Johnson Spaceflight Center, but in the "roles and missions" exercises of the late 1970's, their scientist was forced to leave and made the great discovery instead for a university in New Mexico. It could also have been a Soviet discovery, for the successful technique was the use of a superconducting magnet, and

from Anashkin et al. (1969), we find the paper, "Trial of Superconducting Magnetic System with Field  $H = 20$  kOe on Board an Artificial Earth Satellite." Indeed, Ginzberg and Ptuskin (1981), discussing the origin of these anti-protons, credit Soviet experimenters (Bogomolova et al., 1979) with the discovery as well as Golden et al. (1979).

In short, Soviet cosmic ray investigations in space, while quite active, seem uninspired and not commensurate with the opportunity provided by their excellent access to space.

## D. X-RAY ASTRONOMY

### 1. Introduction

New astronomies arrive in different ways. On the ground, radio astronomy arrived in spite of astronomers, who showed, initially, little interest in this new window on the universe. Ultraviolet astronomy from space was eagerly anticipated by the best astronomers, yet when a physicist, Professor Warren Moos, of the Johns Hopkins University, reported to a gathering of experts on stellar chromospheres (at College Park, Maryland, in the early 1970's) the first rocket observation of the crucial hydrogen Lyman-alpha line from a cool star other than the sun, he was perplexed by the lack of interest with which his observation was received. (That observation was followed by an enormous observational development, using satellites, in succeeding years.) The point is that scientists are human, with all the blindness and narrowness included in the nature of our species.

The arrival of x-ray astronomy provides an extreme contrast. Here was a spectral region (say a hundredth of an Angstrom to one Angstrom; or better, 1 keV to 40 keV) where there was no confident prediction of any detectable radiation at all. Yet bold physicists at American Science and Engineering Corporation, and at the US Naval Research Laboratory, decided to look, with financial support from NASA. The year was 1962--the space age was five years old, counting from Sputnik, 16, counting from the White Sands V-2 program.

The initial rocket flights revealed an intense source of x-rays in the southern sky; a general, apparently diffuse, background of x-rays; and strong x-radiation from the famous Crab nebula. In 1969, Gilbert Franz and his colleagues discovered pulsed x-rays, from the pulsar that had been located in the Crab; and in 1971, the Uhuru satellite discovered a number of x-ray neutron stars. This was followed by the US HEAO program, and the United States is currently planning the Advanced X-Ray Astronomy Facility (AXAF), a permanent x-ray observatory in space.

Apart from the program of planetary exploration, x-ray astronomy provides perhaps the most brilliant and exciting result of our access to space. However, the Soviets have played a small role in this area.

The Soviet Union has astrophysicists who have contributed in deeply important ways to progress in x-ray astronomy, from the point of view of theory. One thinks, first of all, of the late I. S. Shklovskiy; and, currently, of the brilliant R. A. Syun'yayev. Leafing through the European journal, Astronomy and Astrophysics, one finds, for example, in 1979, the paper, "The Profile Evolution of X-ray Spectral Lines Due to Comptonization: Monte Carlo Computation" (Pozdnyakov, Sobol' and Syunyaev, 1979). This paper was followed, in the same journal, by two related papers by Syunyaev and Titarchuk (1980, 1985). These are by no means the only Soviet workers: in the same journal we find in 1985, "The Binary X-ray Pulsar 1E 2259 + 59—Descendant of an AM Her Type System?" by Lipunov and Postnov (1985), and in 1981, "Quantum Theory of Cyclotron Emission and the X-ray Line in Her X-1" (Melrose and Zheleznyakov). These are all first-class contributions, and what they indicate is that the Soviet Union possesses a cadre of scientists who are capable of providing any needed stimulus, and any necessary guidance, for a vigorous exploration of the x-ray cosmos. Yet what do we find? We will detail a feeble experimental program which amounts to hardly more than a pretense of activity. A search of the open literature reveals publications describing results of a number of experiments on a variety of space missions.

## 2. Luna 12

The Space Age is young, and space research is different from general astronomical research in at least one important respect: access to space is (or until recently, was) exceedingly difficult and restricted. This added a "political" dimension to research: it was not so difficult to carry out the research, it was difficult to be allowed to carry out

the research. This has changed in the United States, where in ultraviolet astronomy at this moment, access to space is very easy (the International Ultraviolet Explorer [IUE] observatory is operated for all astronomers very successfully by the NASA Goddard Space Flight Center); in x-ray astronomy, easy access was available at the Einstein Observatory (until it failed), operated by NASA and the Smithsonian Astrophysical Observatory.

To understand present research in the area of space astrophysics, it is important and useful to seek its historical roots. For the Soviet x-ray astronomy program, a good introduction is the paper, "Lunar X-Rays and The Cosmic X-Ray Background Measured by the Lunar Satellite Luna-12," by S. I. Mandel'shtam et al. (1968), in which the results of measurements of soft x-rays emitted by the Moon are reported.

The article references earlier work with Luna-10, and makes clear that the prime purpose of this geiger-counter experiment was "to look for further sources of soft x-rays in the surface layer of the moon, producing x-ray fluorescence under the action of solar x-rays." Data on the cosmic x-ray background are also reported. This cosmic background was a matter of intense interest at the time, as it was felt that it might be of deep cosmological significance. The paper "Diffuse X-Radiation Background in Space," by Vaynshteyn et al. (1968a), reports experimental results of measurements of the isotropic x-radiation background in the energy region  $E > 1$  keV.

This was followed by a "Paper II" (Vainshtein and Syunyaev (1968b), which includes "stop press" reports of work by R. C. Henry and H. Friedman at the US Naval Research Laboratory (NRL). Great interest centered on the possibility that what was being detected was thermal emission from generally-distributed intergalactic gas of sufficient quantity that the universe would be (gravitationally) "closed." The low-energy background studied by Henry and his colleagues has since been proven largely "local" in origin, but the higher-energy background remains enigmatic. This resolution, to the extent that matters have been resolved, is entirely a US matter, with no significant Soviet contribution.

### 3. Kosmos 428

Kosmos 428, launched 24 June 1971, carried a CsI (Tl) crystal 20 mm by 80 mm, surrounded by active and passive shielding. A tungsten collimator restricted the field of view to  $2^\circ \times 15^\circ$ . Such a detector is sensitive to "hard" x-rays, say, 40 to several hundred keV. Some details of the instrumentation and results are given by Bratolyubova-Tsulukidze et al. (1976a). "Galactic center" results (Bratolyubova-Tsulukidze, 1976b) and observations of the source 3U 1700-37 (Bratolyubova-Tsulukidze, 1975) are useful and complement the observations of the US Uhuru "soft" x-ray satellite (the designation 3U 1700-37 above means "third Uhuru catalog, right ascension 17 hours 00 minutes, declination  $-37^\circ$ "). Of greatest interest are the papers, "Hard X-Ray Burst in June 1971" (Babushkina et al., 1975) and "Correlation of Hard X-Ray Source Positions with Globular Cluster" (Bratolyubova-Tsulukidze et al., 1976c). These report a Soviet contribution to a major x-ray astronomy discovery, "x-ray bursts" (not to be confused with gamma-ray bursts, an even more important subject which we have treated elsewhere). This discovery was European, including the important fact that these "bursting" sources were often in globular star clusters (groups of  $\sim 10^5$  stars, very old, in orbit about our galaxy). The exploitation of the discovery was Soviet, US, and European. It is probably fair to say that the most vigorous interpretive work ("are these black holes?"--followed by observational proof that they are not) was from the United States.

### 4. Kosmos 856

The Soviet Kosmos 856 satellite, launched in 1976, carried two independent but identical "x-ray scanners" (32-124 keV). It is noteworthy that this panel was able to identify only a single published paper on this experiment, which is rather similar to the Kosmos 428 experiment described above. The single paper is, however, very interesting: it reports detection on 26 September 1976, of pulsed x-rays from the object that produced the famous 5 March 1979 gamma-ray burst. This "pre-discovery" observation gave a period of pulsing of  $8.6 \pm 0.6$  sec compared with the "discovery" period of  $8.1 \pm 0.1$  sec, i.e., the same within the uncertainty. The "pre-discovery" paper is by Loznikov et al. (1980a).

## 5. Salyut 4

The literature search for this assessment located 11 papers on x-ray astronomy associated with Salyut 4. This is more than we find for any other Soviet mission, and is to be compared with the hundreds of published papers from the US rocket, Uhuru, and HEAO x-ray astronomy efforts. Salyut carried an x-ray spectrometer telescope (Kurt et al., 1976a) which had four x-ray detectors. Three of them, with a combined area of 450 cm<sup>2</sup>, recorded radiation in the 2-10 keV range. The fourth detector, whose area was about 40 cm<sup>2</sup>, recorded x-rays of 0.2-2 and 3.5-10 keV energy. Gas-flow proportional counters with small windows of thin plastic film were used in the detectors. The large-area counters had a Lavsan film 12μ thick, while the counter with a low-sensitivity surface had a polypropylene film 6μ thick. In all the detectors, the field of view was limited by a slit collimator and measured 3° x 10° at half the maximum level of the transmission curve. The energy resolution of the detectors was 20% for photons of 5.9-keV energy. The energy range was divided into six channels: 0.2-0.6, 0.6-0.9, 0.9-2.0, 2.0-3.1, 3.1-6, and 6-10 keV. X-ray photons were also recorded in three integrated channels: 0.2-2, 2-10, and 3.5-10 keV. These parameters are very similar to those of US instruments.

The same paper (Kurt et al., 1976) describes observations of an extraordinary and famous flaring x-ray source near Orion, called A0620-00 (i.e., Ariel 5, a British satellite, 6<sup>h</sup> 20<sup>m</sup> - 00<sup>o</sup>). The Salyut spectrometer provided good spectra in the range 0.28 keV to 10 keV. Useful observations are made of a number of other celestial sources:

**Table IV.4**  
**X-RAY SOURCES OBSERVED FROM SALYUT 4**

<u>Object Observed</u>	<u>Reference</u>
Scorpius (Sco) X-1	Moskalenko et al., 1976a Moskalenko et al., 1976b
Hercules (Her) X-1	Grechko et al., 1976 Beygman et al., 1976a
Cygnus (Cyg) X-1	Kurt et al., 1976b Sheffer et al., 1977 Moskalenko et al., 1980

<u>Object Observed</u>	<u>Reference</u>
$\lambda$ Scorpii	Beygman et al., 1976b
Circinus (Cir) X-1	Klimuk et al., 1976
Several	Novikova et al., 1977.

In each case, these represent useful workman-like contributions, in no way seminal. (Sco X-1 and Her X-1 are interesting x-ray-emitting double stars, while Cyg X-1 and Cir X-1 are binary stars believed to involve black holes. The object  $\lambda$  Sco is simply a star that happens to be near the spot on the sky where an x-ray flare was observed by Salyut 4). The designation "X-n" is historically early. The "n" refers to the order of brightness of x-ray sources in a given constellation, hence Cyg X-1 is the brightest x-ray object in the constellation Cygnus. Looking at the table above, we see that the Salyut "spectrometer-telescope," as it was called, was apparently capable of detecting only the very brightest x-ray sources in the sky (from among the thousands of sources that have been cataloged by US experiments such as Uhuru and HEAO).

Lyutyy (1976) reports ground-based photoelectric observation in support of x-ray observations "from the Salyut 4 orbiting laboratory (May-July 1975) and the far-ultra-violet observations from the Apollo spacecraft during the Apollo-Soyuz Test Project (July 1975)." The object observed was the interesting double star SS Cygni.

## 6. Prognoz 6 and 7

Prognoz 6 and 7 represent further Soviet hard x-ray observations with French collaboration. The description of the Prognoz 6 instrument is given by Rakhimov et al. (1980):

... the lateral detectors contained NaI(Tl) crystals with an active CsI(Na) collimator. Inside the collimator were two detectors separated by a lead spacer. The detector axes on the Prognoz 6 spacecraft were maintained parallel to the vehicle orientation axis; thus one detector scanned the ecliptic near the sun's position while the other scanned the opposite direction.

The Prognoz 7 instrument was little different and is described by Estulin et al. (1981).

All of the authors on this last paper are Soviet (Space Research Institute, USSR Academy of Sciences, Moscow), while the previous paper includes two French scientists as authors. We find a total of five Soviet papers giving Prognoz observations of various objects. The papers are unimpressive, but one of them is notable in that it appears in the prestigious US Astrophysical Journal Letters (Bouchacourt et al., 1984). This letter reports on outburst of the flaring source Centarus X-4, and is written by four French and three Soviet scientists, in that order. The paper references observations of the same flare by others; evidently they did not discover the flare.

## 7. Salyut 7

A paper by Belyayev et al. (1983) tells us that:

... an SKR-O2M x-ray telescope-spectrometer designed for x-ray radiation in the 2-25 keV range is mounted on the Salyut 7 orbital space station (launched April 19, 1982). Proportional counters with a large area for recording x-ray photons--about 2400 cm<sup>2</sup>--are used.

We find no published x-ray astronomy results from this experiment.

## 8. Astron

The Astron spacecraft was launched from Tyuratam by a D-1-e booster on 23 March 1983. It carried a major ultraviolet astronomy experiment, which we discuss elsewhere, and an x-ray astronomy experiment, which is described by Kurt and Sheffer (1984). A photograph of the x-ray experiment is captioned "The SKR-O2M X-Ray Telescope-Spectrometer," so presumably this experiment is identical to the unproductive Salyut 7 x-ray experiment. Samples of the raw data are given, indicating that meaningful data were acquired. There have apparently been no published papers giving x-ray astronomy results from this mission, however.

This concludes our description of Soviet x-ray astronomy experiments. Additional perspective on Soviet interest in aspects of x-ray astronomy can be gleaned from consideration of the following papers:

- "X-Ray Bursters: Their Origin and Evolution," by G. S. Bisnovatyy-Kogan and M. M. Romanova (1983). This of course deals with the theory of the x-ray bursters observed by Kosmos 428.
- "Models for the X-Ray Brightness Fluctuations in Cygnus X-1 and Active Galactic Nuclei," by Bisnovatyy-Kogan and S. I. Blinnikov (1978). The "fluctuations" that are observed are a powerful diagnostic of the nature of the source, probably black holes both in the case of Cyg X-1 (stellar mass) and active galactic nuclei (super-massive).
- "Bursters: A New Type of X-Ray Source or a Property of Old X-Ray Pulsars?" by the distinguished I. S. Shklovskiy (1978). (Self-explanatory).
- "Stellar Wind Flow Around an X-Ray Source," by Krasnobayev and Syunyayev (1977). In most double-star x-ray sources, the x-rays are produced by material ("stellar wind") flowing from a normal star onto a super-dense neutron star. What is observed of course depends on the nature of the flow, which is of great interest.
- "Parameters of the Binary X-Ray System  $3\mu$  0900-40," by Bochkarev, Karitskaya and Shakura, (1975). This is an early contribution, analyzing US data to understand this double-star x-ray source.
- "The Long-Period X-ray Pulsar  $3\mu$  0900-40 as a Neutron Star with an Abnormally Strong Magnetic Field," by Shakura (1975). (Self-explanatory). Incidentally, "abnormally strong" means  $10^{14}$  to  $10^{15}$  Gauss, compared with the earth's 1 Gauss field. Astronomy provides magnetic fields far beyond any that can be produced in the laboratory, and potentially offering insights in fundamental physics.
- "The Ellipsoidality Effect and the Parameters of the X-Ray Binaries Cygnus X-1 and Centaurus X-3," by Bochkarev, Karitskaya, and Shakura (1975b). Calculations regarding the nature of these double stars.

- "Interaction of the Accretion Disk with the Magnetic Field of a Neutron Star," by Lipunov and Shakura (1980). The swirl of material flowing from a normal star onto a neutron star is called an "accretion disk."
- "Spectroscopic Observations of the X-ray Source Cygnus X-2," by Chuvayev (1976). These are ground-based observations made with "the 2.6 m Shain Telescope."
- "An Automodulation Collimator for X-Ray Astronomy," by Loznikov and Yamburenko (1980b), reports "a new design for an x-ray telescope." This paper purports to represent discovery of a technique that in 1980 was well-known in the West.

## 9. Summary of X-Ray Astronomy

When cosmic x-rays were discovered from a small US rocket experiment in 1962, the Soviets were as well poised as the United States, technologically, to exploit the discovery, and they also had the scientific motivation. The eventual appearance of dedicated x-ray astronomy experiments such as the SKR-O2M telescope-spectrometer (now flying on the Soviet Astron mission) indicates some will to participate actively in the exploration of the x-ray universe. The Soviet activity may appear to be so slow as to be unbelievable as a genuine implementation of policy, but the United States has also been very slow to follow up certain major discoveries (gamma-ray bursts;  $3^{\circ}$  K background) in a significant way in space. It is a tough, expensive business. We expect the Soviets to continue efforts in x-ray astronomy, but we expect nothing in the foreseeable future that could in any way compete with the planned (not yet approved) US AXAF permanent orbiting x-ray observatory.

## E. ULTRAVIOLET ASTRONOMY

The promise of space for astrophysics was first of all an ultraviolet promise, because it was a known fact, from simple extrapolation of observations in the visible portion of the spectrum, that many stars radiate most of their energy in the part of the ultraviolet ( $912\text{\AA}$  to  $\sim 3200\text{\AA}$ ) that is not only not accessible from earth, it is not even

accessible, in large part, from balloons. Lyman Spitzer and others recognized this very early and anticipated the arrival of access to space with delight. William Fastie, independent inventor of the Ebert-Fastie spectrometer, reports that his first thought on sighting Sputnik was "that's where my spectrometers should be," and very soon they were.

The first far-ultraviolet spectra of stars were obtained from small rockets by Don Morton and Lyman Spitzer of Princeton University Observatory in the 1960's. As a detector, they used ultraviolet-sensitive film. Early Soviet interest is evidenced in the paper, "Effect of Pre-exposure on Sensitivity of UF-2T Film to Short-Wave Ultraviolet Radiation" (Shpol'skiy and Razorenova 1969). Photoelectric detection of ultraviolet radiation is in many ways preferred, and on planetary missions it is essential. Planetary missions are to observe the planets. If, in the months of travel to the planets, the on-board instruments can do excellent astrophysics, that is a matter for the astrophysicists. The missions cost a great deal of money. This is a "political" matter that has never been globally resolved in the United States: sometimes there is support for "cruise science," as it is called; sometimes there is not. It is not clear how the Soviets manage this matter. Relevant, however, is the paper, "Measurements of Ultraviolet Radiation from Automatic Interplanetary Stations 'Venera-5' and 'Venera-6' " (Belyayev et al., 1970), as it indicates cruise science has been carried out by the Soviets.

Now, in fact, the work by Belyayev et al. (1970) is an important, pioneering paper. It is approximately co-incident with the US OAO-2 satellite work of C. Lillie, and the US sounding-rocket work of R. C. Henry. It clearly represents by-products of investigation of the planet Venus. Of the many US planetary missions that carried ultraviolet experiments, only two (Apollo 17 and Voyager) have been used to carry out any significant ultraviolet astrophysics investigations.

The deepest Soviet interest in ultraviolet cosmic radiation is cosmological--the hope that, say, a possible intergalactic medium might radiate strongly in the ultraviolet and be detectable. The most important US calculations along these lines were carried out by Ray Weymann, but excellent similar Soviet work appeared at nearly the same time.

Since Apollo 17, the US "diffuse ultraviolet" program has consisted of important, but somewhat confusing, work by Bowyer on Apollo-Soyuz, and occasional rocket experiments by him and by the Johns Hopkins University group.

The Soviet ultraviolet-background-radiation program has advanced with French collaboration. For example, a dedicated experiment flown on Prognoz 6 provided an ideal orbit for carrying the Soviet phototelectric spectrometer up to 200,000 km from the Earth. This high altitude is extremely important, because terrestrial airglow and particle contamination continue to exist above, for example, Space Shuttle altitude. The Franco-Soviet results are reported by Zvereva et al. (1981), Severniy and Zvereva (1983), and Zvereva et al. (1982). It appears that excellent data were obtained, but the treatment of the data and the publications are unsophisticated.

A closely related topic of investigation (in terms of observation technique) is the study of interstellar matter flowing through the solar system. The method is to observe solar radiation back-scattered from the interstellar gas. The candidate solar radiation is  $L\alpha$  (which scatters from hydrogen gas) and He 584Å (which scatters from Helium). An excellent Helium experiment was conducted by the Soviets with French collaboration (Dalaudier et al., 1984). It was, however, essentially duplicative of earlier US work.

The Soviet-French study of solar-system  $L\alpha$  is discussed in the paper, "Observed Perturbations of the Velocity Distribution of Interstellar Hydrogen Atoms in the Solar System with Prognoz Lyman-Alpha Measurements" (Lallement et al., 1984). The technique of analysis is described by Bertaux and Lallement (1984), both of whom are French. One uniformly is given the impression that the French are "on top of" the science in a way that the Soviets are not. (It is also clear, on comparing the contributions of different French collaborators, that there is a wide internal range in quality among the French scientists). Evidence of interpretive thought on these topics on the Soviet side is provided by the interesting paper, "The Shift of the Solar 584-Å He I Line, and Evidence for Interstellar Wind from the Interplanetary EUV Background" (Burgin, 1984).

Our discussion of ultraviolet astronomy, so far, has followed Soviet progress in the study of diffuse ultraviolet radiation, a field that, rightly or wrongly, is widely perceived as peripheral in the United States. US interest in the ultraviolet has centered on the radiation of stars. Morton's rocket data were followed by the first OAO (failed immediately); a copy (moderately successful--provided low-resolution spectra of many stars); the Goddard "oceanographic" OAO (launched deep into the Atlantic in 1971); and, finally, Princeton's brilliantly successful OAO-3, called "Copernicus," which provided high-resolution spectra of many stars. The first Soviet stellar results were obtained in 1973 using the space observatory Orion-2, as reported in "Ultraviolet Spectrograms of

Stars Obtained on Orion-2" (Gurzadyan et al., 1974). Other results are reported by Gurzadyan (1974, 1975). The work is competent and the data are of good quality and are interesting, but there are few publications; the work is certainly not in the same league as the US OAO program of that time.

At least one Soviet astronomer, N. A. Sakhbullin of Kazan University, participated in the open "guest investigator" program on the US OAO-3 (Copernicus) observatory. His worthwhile results on mass motions in the atmospheres of the stars  $\rho$  Leonis and  $\kappa$  Orionis are reported in Soviet Astronomy Letters (Sakhbullin, 1977).

The "next generation" of stellar ultraviolet investigation was, in the United States, the International Ultraviolet Explorer (IUE--which carries British detectors) and, in the Soviet Union, the ultraviolet experiment aboard Astron (which carries French detectors). The IUE, launched in 1977, has produced hundreds of excellent publications, while the "Spika" experiment aboard Astron, launched in 1983, has apparently produced one paper so far, "The Ultraviolet Telescope Aboard the Astrophysical Space Station 'Astron'" (Boyarchuk et al., 1984). The telescope on Astron is Soviet, while the spectrometer is French. The paper compares Astron data with Copernicus and IUE data. Samples of Astron data are given, and seem to be of high quality. Were there to be a sustained observation program, large-scale involvement of many observers, and widespread publication of results, this experiment would be a useful addition to the OAO and IUE programs. There is, however, little sign of any of these crucial activities.

The future in ultraviolet stellar astronomy belongs to the Space Telescope. The French, rumor has it, have declined to participate in a next-generation Astron.

As for that step-child, diffuse ultraviolet radiation, the most active US investigators, Bowyer (Berkeley) and the Johns Hopkins group, will fly together on a Space Shuttle mission in some months time. The French scientists who worked with the Soviets plan an experiment for Eureka (the European part of Space Station). All of this is work in low earth orbit, a very poor place indeed to conduct these studies. Given the deep Soviet interest in diffuse ultraviolet radiation, given the Soviet highly elliptical orbits that are ideal for such studies, and given the existence of two US groups technically excellent in the field, but lacking opportunities to place experiments in such an orbit, one concludes that here is a possible area of US-Soviet joint venture, if such is desired.

In summary, the Soviets, in collaboration with the French, are comparable in capability with the United States in the study of diffuse ultraviolet cosmic light, but are far behind in the study of point sources such as stars. These studies may be of peripheral military significance in that ultraviolet sensors on missiles or SDI (Strategic Defense Initiative) defense devices must be programmed to recognize and discount known bright sources of cosmic ultraviolet light, such as stars. An existing SDI subcontract with the The Johns Hopkins University--from the Applied Physics Laboratory at Johns Hopkins--will provide these data in as much detail as could be needed in the foreseeable future.

## **F. OPTICAL AND INFRARED ASTRONOMY**

### **1. Optical Astronomy**

Soviet astronomers have tried to compete with the West in the large-scale instrumentation for optical astronomy. They decided to do so by putting most of their efforts into building the world's largest optical telescope--larger than the Palomar five-meter (in diameter) telescope. The Soviet Union has completed a six-meter (in diameter) optical telescope located near Zelenchukskaya in the Caucasus, only about 20 km away from the RATAN-600 radio telescope. It is fair to say that the construction of this large telescope has been problematic. In particular, the six-meter mirror had to be changed a few times due to imperfections. Also, the large size of this telescope required that it be an altitude-azimuth mounted telescope, compared to the usual equatorial mount (like the Palomar five-meter). This altitude-azimuth system originally presented pointing and tracking problems, but it appears that the telescope has been operating normally for the past two years.

It is surprising that in spite of the huge Soviet effort devoted to astronomy, including the very expansive giant telescopes like the radio RATAN-600 and the six-meter optical telescopes, no pioneering discoveries have been reported. Not even significant observational additions to important areas like pulsars and quasars have been made with the existing large Soviet instruments. However, their telescopes continue to function with a variety of normal projects of general interest.

It is fair to say that the several Western optical telescopes with diameters of 150 inches, including the 200-inch Palomar telescope, have yielded astrophysical data superior to the Soviet six-meter telescope. Similarly, the RATAN-600 radio telescope is significantly inferior to the US Very Large Array or the 1000-ft (in diameter) Arecibo radio telescope.

A number of astronomers from outside the Soviet Union have been assigned observing time with the six-meter telescope. Groups from Great Britain, East and West Germany, France, and the United States (mainly Dr. A. G. Davis Philip, Schenectady, NY) have used the telescope on a number of occasions during the past few years. The permanent staff at the six-meter telescope includes some 50 astronomers (Philip, 1981, 1983). Dr. Philip's visits to the six-meter telescope have been satisfactory for his routine spectrophotometric work on late-type stars. However, he points out that the general technological level of the six-meter facility (i.e., computers, detectors, etc.) is far below the best which exist in the West. The most important drawback of the six-meter telescope, according to Dr. Philip, is its location, where the weather is clear only about one-third of the time (Philip, private communication, 1986).

The Soviet Union has been active in medium size research optical telescopes with reflector diameters between one meter and 2.5 meters. For example, the Byurakan Astrophysical Observatory (Byurakanskaya astrofizicheskaya observatoriya) in Soviet Armenia has completed an excellent 2.5 meter research telescope. More recently, a large astrophysical complex has been initiated in the Zailiyskiy Alatau Mountains near Alma Ata, at 2750 meters above sea level. This facility is directed by the Astrophysical Institute (Astrofizicheskiy institut) of the Kazakh Academy of Sciences. A 1.5 meter (in diameter) telescope is being installed, which was constructed at the Leningrad Optical-Mechanical Association. This telescope will be controlled automatically by a computer, and may be operated with remote control. Plans call for an even larger optical telescope for Alma Ata (Bayzhanov, 1984).

Table IV.5 summarizes the largest optical telescopes in the world to provide a basis for a comparison of the Soviet effort.

Table IV.5  
THE LARGEST OPTICAL TELESCOPES

Telescope or Institution	Location	Diameter (m)	Diameter (in)	Date Completed	Mirror
Soviet Special Astrophysical Obs.: BTA	Caucasus, USSR	6.0	236	1976	Pyrex
Palomar Observatory: Hale Telescope	Palomar Mtn., California	5.0	200	1950	Pyrex
Multiple Mirror Telescope (MMT)	Mt. Hopkins, Arizona	4.5	176	1979	Fused silica
Roque de los Muchachos Obs.: Wm. Herschel Tel.	Canary Islands, Spain	4.2	165	1986	Cer-Vit
Cerro Tololo Inter-American Obs.	Cerro Tololo, Chile	4.0	156	1975	Cer-Vit
Anglo-Australian Telescope (AAT)	Siding Spring, Australia	3.9	153	1975	Cer-Vit
Kitt Peak National Obs.: Mayall Tel.	Kitt Peak, Arizona	3.8	150	1974	Quartz
United Kingdom Infrared Telescope (UKIRT)	Mauna Kea, Hawaii	3.8	150	1979	Cer-Vit
European Southern Observatory (ESO)	LaSilla, Chile	3.6	142	1976	Fused silica
Canada-France-Hawaii Telescope (CFHT)	Mauna Kea, Hawaii	3.6	140	1979	Cer-Vit
German-Spanish Astronomical Center	Calar Alto, Spain	3.5	138	1983	Zerodur
Infrared Telescope Facility	Mauna Kea, Hawaii	3.0	120	1979	Cer-Vit
Lick Observatory: Shane Telescope	Mt. Hamilton, California	3.0	120	1959	Pyrex
McDonald Observatory	Mt. Locke, Texas	2.7	107	1968	Fused silica
Crimean Astrophysical Obs.: Shajn Tel.	Crimea, USSR	2.6	102	1961	Pyrex
Byurakan Observatory	Armenia, USSR	2.6	102	1976	Pyrex
Las Campanas Obs.: Irene du Pont Tel.	Cerro Las Campanas, Chile	2.5	101	1977	Fused silica
Roque de los Muchachos Obs.: Isaac Newton Tel.	Canary Islands, Spain	2.5	101	1984	Zerodur
Mt. Wilson Observatory: Hooker Tel.	Mt. Wilson, California	2.5	100	1917	Plate glass
Edwin P. Hubble Space Telescope	Earth orbit	2.4	94	1986	Fused U.L.E.
Michigan/Dartmouth/MIT Astronomy Consortium	Kitt Peak, Arizona	2.4	93	1985	Cer-Vit
Wyoming Infrared Obs.	Jelm Mtn., Wyoming	2.3	92	1977	Cer-Vit
Mt. Stromlo and Siding Spring Obs.	Siding Spring, Australia	2.3	92	1984	Cer-Vit
Steward Observatory	Kitt Peak, Arizona	2.3	90	1969	Fused quartz
University of Hawaii	Mauna Kea, Hawaii	2.2	88	1970	Fused silica
German-Spanish Astronomical Center	Calar Alto, Spain	2.2	88	1979	Zerodur
European Southern Observatory	LaSilla, Chile	2.2	88	1984	Zerodur

Source: Table adapted from Pasachoff (1985), p. 31.

Although Soviet scientists recognize the importance of making astronomical observations from outside Earth's atmosphere (even at optical wavelengths), they do not seem to have begun significant efforts towards an optical space telescope. In contrast, the United States is about to launch such a space telescope in 1986. The US effort so far has indicated that such a project is extremely expensive and technologically very sophisticated.

## **2. Infrared Astronomy**

It is striking that the Soviets appear to have reported relatively little about astronomical observations in the infrared, at wavelengths longer than  $\sim 2\mu$ . This is not to say that Soviet astronomers are not interested in infrared research. But it does appear that in spite of their efforts, they do not have access to sensitive infrared detectors at 10 or  $20\mu$ . Also, no major Soviet efforts towards infrared astronomical work with high altitude airborne telescopes, like NASA's Kuiper Airborne Infrared Project, have been identified. Soviet astronomers have been very interested in collaborating with Western scientists in infrared astronomy in order to learn the infrared instrumentation and techniques. It is known that astronomers from the Max Planck Institute for Radio Astronomy at Bonn, West Germany, have made infrared observations with the Soviet six-meter telescope.

A submillimeter telescope was carried in the Salyut 6 space station. It is reported that this telescope was tested successfully and that valuable experience was gathered in operating infrared telescopes from space. This instrument has been referred to as the BST-1M submillimeter telescope, and it performed observations of the radiation from Earth's atmosphere, and limited stellar and galactic observations ("Moscow News," 1981; "BST-1M Submillimeter Telescope," 1979).

It appears that some development activity for infrared instrumentation exists at the Physics of the Moon and Planets Laboratory at the Astrophysical Institute in Kazakhstan (Pravda, 1978).

More recently, Soviet scientists have begun discussions on future collaboration in infrared astronomy with the European Space Agency. Plans call for the Europeans to provide instrumentation for the European Infrared Space Observatory covering the wavelength range from 5 to  $200\mu$ , and for the Soviets to cover the wavelength range from  $100\mu$  to 1 mm ("ESA, Soviets Plan Joint Space Research," 1983).

In contrast, astronomers in the United States and Western Europe have made very significant advances in infrared astronomy. Ground-based, balloon, and high-altitude-aircraft infrared observations with sensitive detectors, from wavelengths  $\sim 2 \mu$  to a few hundred  $\mu$ , have been used successfully for a variety of astronomical observations. More recently, the Infrared Astronomical Satellite (IRAS, United States with European participation) has functioned perfectly for one year, producing an extremely large, high quality data bank. US scientists are now working on preparations for a future Space Infrared Telescope (SIRTF) to be launched in the early 1990's.

## G. RADIO ASTRONOMY

### 1. General

Radio astronomers in the Soviet Union represent a very strong force in the scientific community. This is evident by the large number of expansive radio telescopes that have been constructed in the Soviet Union, and by the large number of Soviet scientists working in radio astronomical projects. As an example, the 15th All-Union Conference on Galactic and Extragalactic Radio Astronomy was held in Khar'kov in October 1983, and more than 200 scientists were present. A total of 172 reports were presented at these meetings on a variety of radio astronomical topics of current interest. It was decided that Soviet radio astronomers have an acute need for radio instrumentation at short wavelengths (probably at mm wavelengths) ("All-Union Conference of Radio Astronomers," 1984). Table IV.6 summarizes the radio astronomy observatories operating in the Soviet Union.

### 2. The RATAN-600 Radio Telescope

The major radio astronomy instrument in the Soviet Union is the RATAN-600. It is located near Zelenchukskaya in the northern Caucasus, 20 km northeast of the six-meter optical reflector telescope. This radio telescope was completed in 1979 and has been in operation ever since. The RATAN-600 is of unusual design, consisting of 895 panels that make up a ring 576 meters across. Each panel is 2 x 7.4 meters in size. The total collecting area is 13,000 square meters (or 1/6 that of the Arecibo 1000-foot dish at Puerto Rico). The telescope was designed to work in the wavelength range  $\lambda 8$  mm to  $\lambda 20$  cm. This telescope can measure the positions of radio sources to an accuracy of one to

Table IV.6  
SOVIET RADIO ASTRONOMY OBSERVATORIES\*

			Telescopes	
Name, Location and Altitude	Operating Administration (information contact)	Type, Size and Height	Sky Coverage (degree)	Collecting Area
Byurakan Astrophysical Observatory Byurakan, USSR		<ol style="list-style-type: none"> <li>1) Radio interferometer</li> <li>2) Four fixed cylindrical paraboloids</li> <li>3) 10 m paraboloid</li> </ol>		
Crimean Astrophysical Observatory Simeis, Crimea, USSR 44°43.7' N 34°01.0' E 550 meters	Lebedev Physical Institute Moscow, USSR	<ol style="list-style-type: none"> <li>1) 22 m steerable paraboloid</li> <li>2) 18 x 8 m cylindrical steerable paraboloid</li> <li>3) 19 m steerable paraboloid</li> <li>4) Two 31 m fixed reflectors, used as interferometer with 800 m E-W baseline</li> </ol>		
Pulkovo Observatory Leningrad, USSR 59°46.1' N 30°19.4' E 70 meters		<ol style="list-style-type: none"> <li>1) 16 m fixed paraboloid</li> <li>2) 120 x 3 m parabolic sector</li> <li>3) Two 12 m paraboloids transit mount</li> <li>4) Two 10 x 2 m cylindrical paraboloids</li> </ol>		
Serpukhov Radiophysical Station Serpukhov, USSR	Lebedev Physical Institute Moscow, USSR	<ol style="list-style-type: none"> <li>1) 22 m steerable paraboloid</li> <li>2) Two 1000 x 40 m parabolic cylinders</li> </ol>		
Institute of Radiophysics and Electronics Kharkov, USSR	Institute of Radiophysics and Electronics Ukrainian Academy of Sciences (Prof. S. Ya. Brauda)	UTR-2 telescope in T-dipole array 1860 m, N-S, 900 m E-W	-50° to +50° azimuth -85° to +85° elevation	

(continued on next page)

Table IV.6  
**SOVIET RADIO ASTRONOMY OBSERVATORIES\***  
 (continued)

Name, Location and Altitude	Operating Administration (information contact)	Telescopes		
		Type, Size and Height	Sky Coverage (degree)	Collecting Area
Zimenki Radio Astronomy Station Zimenki, USSR	Institute for Radiophysics Gorkiy State University	Two 15.2 m parabolooids	Full sky	13,000 m <sup>2</sup>
Special Astrophysical Observatory Zelenchukskaya, USSR 43°49.5' N 41°35.4' E	Special Astrophysical Observatory of the Academy of Sciences	895 2 by 7.4 m panels arranged in a ring, 576 m in diameter with a 500 m flat reflector and five secondary feeds	Dedicated to solar research	
Solar Radio Station Siberia, 250 km SW of Irkutsk		256 dish antennas in a cross		

\* Not including ground-based communications antennas.

Source: Table adapted from Committee on Radio Frequencies (1983), p. IV-10.

two arc seconds. The sensitivity at wavelengths between 4 and 8 cm is 0.005 Jansky for a time constant of 100 seconds. The angular resolution of the telescope is  $4 \times 25$  arc seconds at a wavelength of 8 mm, and  $1.6 \times 10$  arc minutes at a wavelength of 21 cm (Korolkov and Pariyskiy, 1979).

The RATAN-600 has been engaged in a variety of radio astronomical research, including a whole-sky survey at centimeter wavelengths, spectra of extragalactic continuum sources such as quasars and radio galaxies, galactic mapping of ionized thermal clouds, observations of the moon, planets, and their satellites, and observations of the solar corona and solar active regions.

It appears that the RATAN-600 is a multi-user, multi-purpose radio telescope, and the Soviet Union has given the highest priority in radio astronomical instrumentation to this instrument. However, this system is very complex and very difficult to calibrate. The RATAN-600 remains significantly inferior to the US Very Large Array (VLA--operated by the National Radio Astronomy Observatory, near Socorro, New Mexico), and to the Arecibo 1000-ft spherical antenna radio telescope (operated by Cornell University, near Arecibo, Puerto Rico).

### **3. Very-Long-Baseline Interferometry**

It is apparent that Soviet scientists put very high emphasis on the radio astronomical technique called "very-long-baseline interferometry" (VLBI). They consider VLBI and aperture synthesis to be extremely important and have taken great interest in implementing such activities even with space radio telescopes. The power of these techniques is in providing extremely high angular resolutions, thus enabling the detailed mapping of radio sources.

During the past 15 years, international collaboration has made possible the simultaneous use of radio antennas on different continents. Soviet radio astronomers have participated in such efforts with the use of their 22-meter steerable parabolic radio telescope located at the Crimean Astrophysical Observatory (Krymskaya astrofizicheskaya observatoriya--at Katsivelli, a village in the Crimea).

More recently, Soviet scientists have developed a VLBI system at a wavelength of 1.35 cm (corresponding to the molecular line radiation of H<sub>2</sub>O) using the 22-meter Crimean telescope and an identical one at Pushchino operated by the Lebedev Physics Institute (Fizicheskii institut imeni P. N. Lebedeva--located near Serpukhov, south of Moscow). The two telescopes are 1150 km apart, located in a north-south direction. The best resolution obtained with this system has been 0.002 arc seconds at a wavelength of 1.35 cm.

In order to perform VLBI experiments, the measurements at each telescope must be compared with extremely high time accuracy. The Soviet team has used as a reference signal a hydrogen frequency standard which is stable to better than  $10^{-14}$  over a period of 1000 seconds. In the period of several days, this system maintains time to a precision of  $\leq 0.1 \mu\text{sec}$  (Matveyenko et al., 1980).

Soviet scientists have investigated performing aperture synthesis using a radio telescope in space. They have discussed the great potential of building extremely large antennas in space for high sensitivity, and by placing these antennas very far apart, achieving unprecedented angular resolution. N. S. Kardashev, S. V. Pogrebenko, and G. S. Tsareveskiy (1980) have described an aperture synthesis system utilizing a ground based radio telescope and one in space at an altitude between 300 and 400 km. These authors show that such a system is superior to a ground-based multi-element aperture synthesis telescope (like the VLA and VLBI).

Corresponding to their emphasis in VLBI and aperture synthesis in space, the Soviets surprised the world radio astronomical community when, on 18 July 1979, the Salyut 6 Space Station deployed a 10-meter (in diameter) erectable "umbrella" radio telescope, the KRT-10. This telescope was delivered by the Progress 9 automatic cargo craft, was assembled by the cosmonauts, and was deployed in space (after some difficulty, as the antenna was caught up on a projection of the space station). This first space radio telescope was used in conjunction with the 70-meter ground-based radio telescope on the long-range space communications center in the Crimea (Kidger, 1979, 1980).

The KRT-10 was supposed to work with the Crimean ground-based 70-meter telescope in the VLBI mode to study astrophysical sources. The results of such observations do not seem to have been reported in any detail. However, it was reported that the KRT-10 was directed towards the sun, the Milky Way, and a pulsar. The operational wavelength for this experiment was  $\lambda$  18 cm, corresponding to the OH

molecular transitions from interstellar sources. There are also indications that the KRT-10 was operational at wavelengths of  $\lambda 12$  and  $\lambda 72$  cm, and that it was also used for radio cartography of the earth's surface and oceans (Zakson and Sokolov, 1980).

The Space Research Institute (Institut kosmicheskikh issledovaniy) in Moscow has been preparing a three-meter radio antenna to operate at a wavelength of  $\lambda 1.35$  cm, corresponding to the H<sub>2</sub>O molecular transition from interstellar masers. This telescope is to be launched into space and is supposed to work with ground-based telescopes in the VLBI mode (Kostenko and Matveyenko, 1982). It is also possible that Soviet radio astronomers may be preparing a Space Very Long Baseline Array involving several space antennas. Such a system would be superior to any of the ground-based systems.

#### **4. A New Solar Radio Telescope in Siberia**

During 1984, Soviet solar radio astronomers completed a large new radio telescope devoted to the study of the sun. This instrument is located in Siberia, 250 km southwest of Irkutsk. The telescope is a cross radio antenna, with each beam 500 meters long, made by 128 dish antennas. The east-west antennas are already operational, and the whole cross (256 antennas) will be ready soon. This instrument is designed to have a resolution of  $\sim 20$  arc seconds at centimeter wavelengths, and will be able to produce two-dimensional radio maps of the sun every three to four minutes ("Radio Telescope with 256 Antennas Built in Siberia," 1984).

#### **5. Prognoz 9 and the Relikt Experiment**

One of the greatest discoveries of this century has been the detection of microwave background cosmic radiation by Penzias and Wilson (1965). This 3K radiation is supposed to represent the remnants of the hot Big Bang primordial explosion of some 20 billion years ago. To a high accuracy, this background 3K radiation is uniform in the universe. However, any anisotropy would represent vital clues as to the global structure of the universe.

During the past ten years, ground-based, high-altitude balloon and aircraft observations from the United States have found a dipole anisotropy in the cosmic background due to the motion of the solar system with respect to the background. Any quadrupole components remain uncertain.

N. S. Kardashev, a Soviet theoretical astrophysicist, realized late in the 1960's that a modest space experiment can produce very sensitive measurements of background cosmic radiation. On 1 July 1983, the Soviet Union launched the Prognoz 9 satellite, which carried the first space 8-mm wavelength radiometer system to map large-scale anisotropy of the cosmic background radiation. Prognoz 9 was launched on a high apogee orbit of 700,999 km. The 8-mm receiver was of Dicke-type with a degenerate parametric amplifier, and with a system temperature of 300K.

The results of the Relikt experiment after one year of observations indicate that the amplitude of the background dipole and any quadrupole component is measurable to 0.1 mK rms accuracy; and also that, with 95% confidence, the areas of the sky investigated exhibit no quadrupole component above the 0.2mK level. This important experiment is still in progress (Strukov and Skulachev, 1985).

#### **H. SETI: SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE**

The search for extraterrestrial intelligence (SETI) began in a scientific manner in 1959, when physicists Philip Morrison and Giuseppe Cocconi suggested that radio waves present the easiest way for communication with other intelligent civilizations on other planets. During the decade of the sixties, the United States played a unique role in developing the theoretical ideas for SETI and also in trying some practical experiments for listening to a few other stars which might have planets with intelligent life around them, using radio telescopes and available radio astronomical instrumentation. During this time, the only prominent Soviet scientist who discussed and popularized SETI was the late theoretical astrophysicist, Josef S. Shklovskiy.

Early in the 1970's, a joint US-Soviet National Academies of Sciences meeting was held on SETI at Byurakan, Soviet Armenia, and since then, Soviet scientists have shown remarkable interest in this subject. In 1981, a symposium was held in Tallinn (Soviet Estonia) to which the Soviet scientists invited active SETI experts from around the world. The number of US scientists participating in the Tallinn meeting was only ten, compared to more than 100 Soviet scientists. This may, in part, reflect a diminishing interest in SETI by US scientists; however, it is clear that if SETI had had more financial resources, the US delegation could have been larger.

Most of the Soviet effort in SETI has been theoretical. Shklovskiy has argued that the absence of clear evidence of super-intelligent civilizations speaks for the great scarcity of life on other planets. N. S. Kardashev has suggested that the most promising places to search for SETI are the central portions of galaxies. Since 1970, limited SETI experiments have been conducted by Soviet scientists. However, an impressive program for future work was presented at the Tallinn meeting. V. S. Troitskiy described a SETI dedicated radio facility with 100 antennas of one-meter diameter each operating at a wavelength of 21 centimeters and so designed as to allow continuous observation of the entire sky above the horizon. Kardashev described the construction of a major radio telescope near Samarkand (Uzbek SSR). This parabolic full-steerable radio telescope will have a diameter of 70 meters and will be capable of operating at millimeter wavelengths. When completed, it will be the most powerful such instrument in the world. This telescope will devote substantial observation time for SETI according to Kardashev. In Tallinn, it was also reported that a second space launching of a 10-meter radio telescope will take place--to be used as an interferometer with ground-based radio telescopes. In addition, a new Soviet satellite was being planned to make infrared observations of galactic nuclei for possible detection of artificial signals (Drake, 1982; Lomborg, 1982).

The Tallinn meeting indicated that Soviet scientists regard SETI with great enthusiasm and give it high priority. They are prepared to commit themselves to decades of patient observation. However, it was also clear that there is a definite difference in intellectual discipline between the US and Soviet studies of SETI. Many Soviet presentations led to the conclusion that there was far too little mutual criticism and peer review in Soviet sciences.

It should be clear that any SETI success, no matter how accidental, might play an incalculably important role for the nation which first succeeds in identifying extraterrestrials. Would the direction in the sky and the frequency be kept "top secret"? If so, it is conceivable that other countries might take many years, even with suddenly heavily-funded programs, to locate the source, while one country might enjoy private access to a stream of super-high-technology information.

SETI is one area that we can identify where a Soviet breakthrough of "greater than Sputnik" proportions is possible. Furthermore, there is no way to calculate the absolute probability of such a breakthrough. Whatever its value, however, the probability is surely almost directly proportional to the extent of the effort, and we have seen that the Soviet effort is rapidly increasing in magnitude.

**CHAPTER IV: SPACE ASTRONOMY AND ASTROPHYSICS**  
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## CHAPTER V LIFE SCIENCES

### A. INTRODUCTION

Since the beginning of the "Space Age," both the United States and the Soviet Union have rapidly accelerated their respective efforts in both manned and unmanned spaceflight. Over the years, both nations have put primary emphasis on developing the appropriate technologies to accommodate human passengers, and both are moving along lines to guarantee unlimited human occupation of space.

As a consequence of this goal, both nations have conducted, and continue to conduct, both ground-based and space-borne experimental programs in the life sciences. In the United States, these studies--i.e., those related to human spaceflight--are the province of space medicine and operational medicine. For the most part, other, more fundamental, life sciences programs are generally regarded to be largely independent of this mainstream activity. By contrast, the Soviets relate virtually everything they do in the life sciences to the ultimate goal of unlimited human spaceflight.

As will be seen, the Soviets have invested substantial effort and resources in life sciences R&D. Not only have they maintained rigorous medical overview of all of their manned spaceflights, using each one as a vehicle in which to conduct medical investigations, but they have also used almost all of these as opportunities to expose an enormous variety of other biological specimens to the effects of spaceflight. In addition they have provided their life scientists the opportunity to participate in dedicated unmanned space missions, on a steady and frequent schedule.

It is clear that the Soviet effort in this area is formidable. However, what may not be obvious, but is nevertheless very important, is that in many key areas they appear to have the luxury of examining in detail several, alternate, technical strategies. Thus, for example, at the same time that Soviet scientists are probing the effects of weightlessness on living organisms, they are also conducting a substantial program of research on artificial gravity. While they are studying the effects of radiation on living systems,

they are also investigating physical methods of shielding against radiation and biochemical methods of controlling radiation damage in the body. While the Soviets work toward the goal of a regenerable life support system, they are simultaneously pursuing at different institutes separate, divergent, schemes for bioregeneration.

In the Soviet Union, the major force behind the life sciences activities emanates from the Biomedical Problems Institute (Institut mediko-biologicheskikh problem) in Moscow. Here is centralized the technical (scientific and engineering) cadres for both the manned and unmanned life sciences missions. It would appear that this institute generates the directions for the life sciences research strategies needed to accomplish the objectives of the Soviet space program. With regard to the implementation of these objectives, another noteworthy attribute of the overall Soviet strategy is that they appear to have truly long-term plans with milestones along the way. One mission seems to provide information of use to the next one, so that there is a step-wise accretion of knowledge and experience, with the result that each mission seems to have a place in some overall "grand plan."

While the approaches of the United States and the Soviet Union are rather different, along with the scale of their respective efforts, the substance in space life sciences research is not radically different. The major effort in both nations is directed toward the health and performance of their space passengers. Tangential to this central core, there are divergences between the two programs, as discussed below. Thus, while there are large areas of similarity, a strict comparison of US and Soviet space life sciences activities is not feasible. As will be seen in the discussion below, each nation includes certain fields as part of its life sciences effort that are not shared by the other in this context. For the sake of comparison, therefore, the subject matter below will be treated in four major sections: science, space medicine, operations, and applications.

## **B. SCIENCE**

From the point of view of the total spectrum of life sciences activities in space, perhaps the greatest difference between the US and Soviet programs is in the arena of fundamental science. On the US side, there are specific, well-defined science objectives that are largely independent of the manned space effort. By contrast, since the entire space life sciences establishment on the Soviet side is centralized in the Biomedical Problems Institute--whose principal pursuit is to support the manned effort--the fund-

amental biological sciences do not have a significant existence apart from the mainstream. For example, while the Soviets have flown a huge variety of biological specimens, both on manned (Vostok series, Voskhods, Soyuz series, Soyuz-Apollo, Soyuz-Salyut) and unmanned (Zonds, Kosmos series) spacecraft, the rationale and justification for these have, almost without exception, been derived from their expressed goal of achieving unlimited human spaceflight.

## 1. Exobiology

In the United States, exobiological research concerns itself with the evolution of organic matter in the universe--from the formation of the biologically important elements in stars to the development of living systems and the search for extraterrestrial intelligence (SETI). Within this broad evolutionary range, the major thrust is to gain an understanding of the origin of life on Earth. In this context, it is paradoxical that a Soviet biochemist, A. I. Oparin, was the first to propose a plausible theory of chemical evolution to explain the origins of terrestrial life (Oparin later became director of a large institute, the A. N. Bakh Biochemistry Institute [Institut biokhimii imeni A. N. Bakha], where research on the origin of life is a major enterprise); yet this area of the life sciences has not been incorporated into the mainstream of Soviet space activities. Presumably, this is attributable to the fact that this field has no particular bearing on the goal of assuring the permanent presence of humans in space, and thus has no direct relation to the main mission of the Biomedical Problems Institute.

Nor has exobiology made any significant inroads into the Soviet planetary program. From what the Soviets appear to be contemplating for their proposed planetary missions over the next decade--to Mars (Phobos-88), comets (Vega 1 and 2), and asteroids (Vesta-91)--no instrumentation capable of identifying organic molecules is planned for inclusion (Chapter II, this report).

While experiments on the status of chemical evolution on solar system objects do not seem to be of sufficient interest in their program, the Soviets have, on several missions, exposed biological materials to the direct environment of space. Such experiments have usually had, as their basis, an inquiry into what deleterious effects might be expected from radiation and/or vacuum conditions. However, in the "Meduza" experiment mixtures of amino acids, and of DNA (deoxyribonucleic acid) and RNA (ribonucleic

acid) precursors (nucleotides?) were exposed to solar ultraviolet (UV) and cosmic radiation aboard Salyut 6 for 10 months to test whether polymerization of molecules would occur (Konovalov, 1978; Ovcharov, 1978; Khenokh et al., 1984).

The Soviets have also had a long and continuing interest in the question of life on Mars. In 1970, well before the US Viking mission, they published under the editorship of A. Imshenetskiy, of the Institute of Microbiology (Institut mikrobiologii) in Moscow (Imshenetskiy, 1970), a wide-ranging collection of their concepts for life detection. This institute has continued a very active program of "Martian biology" from several points of view. First, these Soviet scientists have analyzed the Viking biology data and offered their own explanations for the results (Imshenetskiy and Murzakov, 1977; Imshenetskiy et al., 1978; Imshenetskiy et al., 1979; Imshenetskiy et al., 1981), concluding that the presence of life on Mars could not be rigorously ruled out. Other Soviet laboratories have also been involved in interpreting the Viking biology results (Garbuz et al., 1982; Aksyonov, 1979) and have reached similar conclusions. Second, the institute scientists seem to be developing additional concepts of life detection (Imshenetskiy et al., 1983). Third, they are actively assessing the chances of growth of terrestrial organisms on Mars (Imshenetskiy et al., 1984; Imshenetskiy et al., 1985). All of these activities are consistent with the statement, ". . . The experimental studies to search for life on Mars, which were undertaken by the American unmanned Viking-1 and Viking-2 stations are only the beginning of extensive future studies that will be pursued by means of space stations" (Imshenetskiy et al., 1983). Soviet interest in the further probing of Mars for the possible presence of life thus appears to be of great interest--at least in certain sectors of the Soviet scientific establishment. Yu. Zaytsev, of the Space Research Institute (Institut kosmicheskikh issledovaniy), reiterated this theme and further suggested that an international cooperative effort would accelerate this objective (Leningradskaya Pravda, 1982).

It should be noted that, despite the intensive Soviet emphasis on Venus in their planetary program during the past decade, no speculations have appeared concerning either the possibilities for life on Venus (or in its atmosphere) or the possibility of terrestrial organisms surviving in some Venusian environment.

The Soviets also appear to be interested in the "panspermia" hypothesis (an alternative to the Oparin concept of the in situ origin of life on Earth), although their studies have been confined to ground-based approaches to this problem (Lysenko, 1981; Nussinov and Lysenko, 1983). They conclude that radiation and vacuum in space would preclude the survival of organic-based organisms in interplanetary or interstellar space.

## 2. Space Biology

### a. Introduction and Background

The term space biology is used differently in the United States and the Soviet Union. Generally speaking, in this country space biology refers to biological experimentation, on orbital vehicles, using organisms other than humans. By contrast, the Soviets tend to include any biological experimentation in space as the domain of space biology. Thus, they include exobiologic issues--and even space medicine--as within this area of study. Since exobiology and space medicine are treated separately in this report, the succeeding discussion of Soviet space biology will focus on those activities that more-or-less parallel US efforts in space biology.

After studying the components of the Soviet program, several generalizations can be made at the outset. First, the Soviets have devoted--and continue to devote--substantially more effort to this field than does the United States. Their "program" of orbiting biological materials takes advantage of virtually every manned spaceflight that is launched, along with equipment and procedures to study human biomedical problems. Non-human biological materials, including plants, animals, and micororganisms, have been aboard virtually all manned missions.

In addition, dedicated biological satellites in the Kosmos series (Kosmos 110, 368, 605, 690, 782, 936, 1129, 1514, and 1667) have been flown on an almost regular basis (i.e., just about every two to three years). These spacecraft have carried microorganisms, tissue cultures, plant seeds, higher plants, insects, amphibians, fish, bird eggs, turtles, rats, and primates.

Taking an overall view of these flight experiments, it is clear that each flight builds on the results of previous flights, and that the Soviet approach is a step-wise process (i.e., a program). Thus, for example, after several earlier flights in which rats

were used--and after obtaining a fairly complete picture of the general nature of the physiological, behavioral, and morphological changes brought about by spaceflight--the Soviets then began to ask (experimentally) whether artificial gravity would prevent or modify any of these changes. This led them to the development of centrifuges for space experiments on Kosmos 936 (Adamovich, 1980). In turn, the development of these animal centrifuges took advantage of information gained from the earlier Kosmos 782 mission, in which a simpler centrifuge was flown first.

Secondly, there is a clear interplay between data that is obtained using flight animals and the data from humans. Perhaps this is because all of these activities are centralized under the aegis of the Biomedical Problems Institute. As Oleg Gazenko, its director, has said:

. . . The obtained experimental data very obviously show that development of any preventive measures against the deleterious effects of weightlessness is impossible without in-depth studies of the mechanisms of occurrence of structural and functional changes in the most vulnerable physiological systems of man. These systems include, first of all, the cardiovascular, vestibular analyzer and skeletomuscular system. . . . To solve these problems, there must be continued broad studies with the use of invasive methods, that open the way toward direct recording of blood pressure and blood flow in vessels, studies of neuronal activity of different afferent and efferent systems, etc. Of course, these problems can be solved the most effectively on experimental animals whose organization is closest to man and for whom the most refined and informative physiological and neurophysiological methods have already been developed. . . . Ultimately, the choice of objects to be studied on biosatellites will be determined, we believe, by the specific objectives of the studies and methods of reaching them. . . . (Gazenko, 1981).

Third, while the biological effects of spaceflight investigated by the Soviets cover a broad range and include a vast array of organisms, there is a general unifying theme that ties almost every payload either to the problems associated with human spaceflight or to the ultimate utility of a biological regenerable life support system for human spaceflight.

#### b. Payloads That Have Been Flown

A thorough review of the results of Soviet space biology experiments and missions is beyond the scope of this report. For this, the reader is referred to the following publications (see Chapter V references) that summarize various aspects of this field:

- For overall, general reviews: Burnazyan et al., 1979; Gurovskiy et al., 1980; Nikolayev and Ilyin, 1981; Tairbekov and Parfenov, 1981; Tairbekov et al., 1981; Gazenko and Parfenov, 1982; Parfenov, 1982; Dubinin, 1984; Gazenko and Ilyin, 1984.
- For summaries of various spaceflight effects on muscles of rats: Belitskaya, 1979; Rokhlenko and Savik, 1981, Ilyina-Kakuyeva and Portugalov, 1981; Savik and Rokhlenko 1981; Oganov et al., 1981; Mailyan et al., 1982; Vlasova et al., 1982.
- For summaries of various spaceflight effects on rat bones: Popova and Tigranyan, 1981; Prokhonchukov et al., 1982; Prokhonchukov and Peschanskiy, 1982; Popova, 1983; Prokhonchukov et al., 1983.
- For the bloodforming system: Pantev et al., 1980; Benova et al., 1984; Shvets et al., 1984.
- For reactions to stress and assays for hormones: Kvetnyanskiy et al., 1980; Kvetnyanskiy and Tigranyan, 1981; Kvetnyanskiy et al., 1982; Komolova et al., 1982; Tigranyan et al., 1982; Knopp et al., 1983; Serova, 1983.
- For animal behavior following spaceflight: Livshits et al., 1978; Shipov and Ovechkin, 1980; Kotovskaya and Shipov, 1980; Apanasenko et al., 1983.
- For biochemical analyses of various tissues, including assays for enzymes, DNA, and RNA in certain tissues: Nosova et al., 1981; Vlasova et al., 1981; Tigranyan et al., 1981; Nesterov et al., 1981; Ahlers et al., 1982; Kurkina and Tigranyan, 1982; Misurova et al., 1982a; Misurova et al., 1982b; Skottova et al., 1982.
- For histological and morphological changes observed after spaceflight: Yakovleva, 1978; Kaplanskiy and Savina, 1981; Rokhlenko and Mul'diyarov, 1981.

- For growth and metabolism of plants during weightlessness: Nevzgodina et al., 1981; Merkys et al., 1981; Tairbekov et al., 1982; Delone et al., 1982; Delone et al., 1983; Kordyum et al., 1984; Merkys et al., 1984; Vaulina et al., 1984.

c. General Conclusions of Soviet Space Biology Experiments

As a result of scores of experiments performed on both manned and unmanned spacecraft, covering the biological spectrum from single-celled organisms and viruses to higher plants and animals, the Soviets have concluded that weightlessness has no significant effect on unicellular organisms. Indeed, they have reported that for many microorganisms growth seems to be somewhat enhanced in space, compared with ground controls. (In general, these conclusions are consistent with US space experiments.)

The growth of plants, from seed-to-seed, has been an objective in Soviet work for some time. Only recently have they succeeded in this endeavor in a single case, the simple plant, Arabidopsis. Overall, they have experienced great difficulties in the "normal" cultivation of most plants in space. During their research on plants, they have noted (as have US scientists) that, for many plant species, weightlessness leads to abnormal growth and disorientation.

With insects, which the Soviets have studied intensively, no significant effects of spaceflight have been noted. Flies have been mated in the zero-G (zero-gravity) environment; the offspring of these insects have been studied; and Soviet researchers have followed flies that lived through their entire life cycle in weightlessness. In recent flights, they have attempted to determine the "gravity preference" of fruitflies (more below, under Artificial Gravity).

Certain reversible disturbances in the development of fish and amphibians as a result of spaceflight have been described by the Soviets. During the growth of embryos of these organisms, the severity of the effects was found to be greatest during the earliest stages of embryogenesis.

Soviet scientists have concluded (as have US scientists) that there do not appear to be any genetic effects of weightlessness per se. Nor does there seem to be any additive effect of weightlessness and radiation--in space--on biological organisms.

The Soviets feel strongly that--in higher plants and animals--gravity probably does not affect intracellular processes, but that specialized systems to sense gravity in these higher organisms signal other parts of the organisms during weightlessness and lead to secondary physiological or behavioral adjustments.

Using rats, for the most part (but also turtles, dogs, quail, and most recently, non-human primates), the Soviets have consistently demonstrated that spaceflight leads to losses in muscle and bone, to anatomical changes in the myocardium (of rats), along with other cardiovascular readjustments. They have also conducted numerous studies, using animals, pertaining to the energy metabolism of higher organisms, and have shown (generally reversible) deviations from normal during "adaptation" to zero G.

The Soviets have also shown that normal development of a fetus occurred when pregnant rats were exposed to weightlessness for about a third of their gestation period, during a period when active formation of organs normally takes place.

#### d. Probable Future Space Biology Activities

Given the past history of this area of the life sciences, there is every reason to expect that the Soviets will continue to put non-human biological payloads into space. For example, quite recently, on 10 July 1985, the Soviets launched Kosmos 1667, which was a repeat of the payloads carried by Kosmos 1514 (two primates, ten pregnant rats, various plant specimens and fish). This latest mission is thus part of the continuing Soviet inquiry into the consequences of weightlessness on various living systems. It is likely that the Soviets will emphasize musculoskeletal problems in future work in space, building on their experience with rats and rhesus monkeys.

They will also probably increase their use of plants for "space biology" payloads, as specific technical problems begin to be narrowed down--problems generated by ground-based studies in which plants are used in regenerable life support systems (see discussion below).

Also, it is to be expected that the Soviets will expand their use of space-borne centrifuges as part of their program to assess the feasibility of providing artificial gravity for truly extended missions of the future.

e. Key Differences Between the US and Soviet Programs in Space Biology

First, it is obvious that the Soviets have a well-developed program of space biology, with clear, long-range goals. They have had, and continue to have, enormously more opportunities to research this area than the United States. Indeed, US biologists have participated in Soviet biosatellite missions (Kosmos 782, 936, 1129, 1514, 1667) to a large extent because "it was the only game in town."

Second, as mentioned above, the Soviets view animal experimentation as an integral part of their R&D efforts to guarantee "permanent occupancy" of space.

Third, in a similar vein, access to space by Soviet botanical specialists is considered to be vital and an important part of their program to solve the regenerable life support problem.

Fourth, unlike the United States, the Soviets have a relatively large and integrated effort to study the use of artificial gravity to prevent or minimize problems associated with weightlessness in both plants and animals. (The broad outlines of the Soviet program are given in the work by Kotovskaya et al., 1981.) Using centrifuges in space, bone demineralization in rats was said to be largely prevented compared to weightless animals (Stupakov, 1981); artificial gravity was claimed to have "normalized" the function of the heart, and also of the excretory and musculoskeletal systems; and centrifugation in space was seen to be an effective general countermeasure against the adverse effects of prolonged weightlessness (Gurovskiy et al., 1980; Gazenko et al., 1980). Biochemical changes seen in weightless animals were also found to be prevented by centrifugation (Ahlers et al., 1982; Abraham et al., 1981).

Fifth, the scale of Soviet activities to research the myriad issues related to the development of regenerable life support systems is truly impressive when compared with the US effort. Many Soviet laboratories and institutes are engaged in research in this undertaking. Both ground-based and space-borne experimentation contribute to these studies. In addition, over the past two decades, facilities have been developed, notably within the Biomedical Problems Institute in Moscow, and at the Physics Institute (Institut fiziki imeni L. V. Kirenskogo) in Krasnoyarsk (Siberia), to conduct large-scale tests of various concepts for closed systems. The variety of issues being studied is extremely broad. Some interesting examples are: the possible use in such systems of Azolla

pinnata (a rapidly growing fern that lives symbiotically with blue-green algae capable of fixing nitrogen [Shepelev et al., 1983]); of housefly larvae (for human waste disposal [Golubeva and Yerofeyeva, 1981; Nosov and Golubeva, 1983]); and of Japanese quail (because of high egg yield and rapid growth [Shepelev et al., 1979]). Much research has been done with the green alga, Chlorella vulgaris, which, along with Azolla flies (fruitflies rather than houseflies) and Japanese quail, have also been flown in space missions to study some of their characteristics in weightlessness.

Many ground-based "demonstrations" have been conducted over the years in which animals and photosynthesizing organisms were isolated in closed chambers to study the problems inherent in such closed systems. In general, such studies at the Biomedical Problems Institute have focused on the use of cultures of the green alga, Chlorella; while at Krasnoyarsk, the effort has gravitated toward the use of mixtures of higher plants. In these demonstrations, first with the use of animals, and then more recently with men, these groups have incrementally increased Soviet confidence in the ultimate solution to this problem with their continued research. To illustrate this point, the Soviets recently completed a full-scale demonstration in which two men were confined for five months in the "Bios-3" facility at Krasnoyarsk, together with about 20% of the total food they required. Air, water, and the remaining foods were cycled within the facility (which had a volume almost as large as Skylab--315 m<sup>3</sup>). To provide food and oxygen, special "phytotrons" (plant growth chambers) grew a variety of plants--including wheat, peas, kohlrabi, rush nuts, dill, and tomatoes--in a total planting area of about 60 m<sup>2</sup> (Vasil'yev 1984; Ivanov and Zuboreva, 1985).

From results such as these, it seems reasonable to conclude that the Soviets, with an empirical approach to the problems, have made substantial progress towards the goal of self-sufficiency in long-duration manned flights. It remains to be seen whether the life support systems and technologies that they have developed will be effective in a weightless environment or whether for these they will have to resort to the use of artificial gravity.

### **3. Global Biology (Biospherics)**

While this area is not considered to be within the purview of the current report, brief mention is made of it here--for the sake of completeness.

Biospherics (or global biology) is a relatively new science component of the US space life sciences. Here, the long-range goal is to understand the interaction between living organisms and the earth on a global scale. Inherent in the approach is that remote sensing of the entire globe will be required to uncover the fundamental ecological relationships between the biosphere and the physical planet.

In this regard, one must note that the Soviets have been conducting remote sensing studies for many years from both manned and unmanned spacecraft for the purpose of identifying and quantifying biological materials. The scope of this research has included investigations of vegetation cover (Kottsov, 1984); soil characteristics (Vasil'yev and Polvarshinova, 1983); humus content of the soil (Kondratyev and Fedchenko, 1984); crop identification (Kondratyev and Fedchenko, 1982); and methods to estimate the chlorophyll content of plants (Kondratyev et al., 1982).

### **C. SPACE MEDICINE**

From the point of view of human physiology, the United States and the Soviet Union have two very different problems. The United States currently flies many short-term missions, requiring intensive workloads throughout the mission. By contrast, the Soviets have protracted missions lasting many months, and do not place much burden on individuals during the first couple of weeks of these flights. As the United States enters the space station era of three-months-duration flights, and as the Soviet Union launches its version of Shuttle, we will both come to common sets of physiological problems. One nagging larger question is whether the goal should be to completely condition crew members to space or whether they would be better off with minimum adaptation, so that they might readapt more easily when they come back to a one-G environment. At present, the Soviets see no logical answer to this (Beregovoy et al., 1982).

#### **1. Cardiovascular Deconditioning**

The cardiovascular system is studied more intensively by the Soviets than any other body system. They take the observed changes very seriously and have accumulated a great deal of data and information as a result of their long-term missions. The US short-duration missions require only that the astronauts perform for a week or so (during the

period of weightlessness when this system is undergoing its initial period of adjustment). As the missions increase in length, the United States will have to expend more effort to understand possible long-term changes.

During spaceflight, significant physiological changes occur to the cardiovascular system. The absence of gravity results in a change in the hydrodynamics of the circulatory system. The body responds with a series of complex reactions in order to try to restore the stable dynamic state. The complete dependency of the body on the cardiovascular system has resulted in a highly dependable and responsive system of delivering nutrients to the rest of the vital areas of the body, e.g., the brain.

Upon exposure to lowered gravity, some of the blood shifts from the lower extremities to the upper torso; this causes an increase in the pressure of the venous return. There is an increase in heart rate, an increase in the stroke volume of the heart, and this results in an increased cardiac output. The physiological response to this is a lowering of the total blood volume through normal kidney filtration function. During space flight, these adaptations are quite smooth, and no discomfort or physiological compromise is experienced. The adaptation to the lower G environment appears to be completed in several weeks.

Upon return to the one-G environment, other problems arise. The lowered blood volume now results in an orthostatic intolerance when uncorrected. The rapid return to one G with the lowered blood volume causes a lowering of perfusion to the brain and subsequent fainting and a rapid heart rate.

The Soviet biomedical researchers have performed extensive research in this area (Yegorov et al., 1984). They have made numerous measurements on the cosmonauts before, during, and after their flights, and have dedicated two of their recent unmanned Kosmos flights (Kosmos 1514 and 1667) to instrumented primates in order to make extensive measurements to better understand the physiology of the cardiovascular system.

Both the United States and the Soviet Union physiologists prescribe similar temporary countermeasures during re-entry. Just prior to the re-entry phase, crew members are instructed to take about a liter of isotonic saline by mouth to return the plasma volume of the blood to normal. This lasts long enough to overcome the temporary

changes during the returning phase to one G. After their long-duration missions, the Soviet crew members' cardiovascular system gradually (days to weeks) returns to normal through a rebuilding of the body fluids to their original values (Yegorov et al., 1983).

Soviet echographic studies show that there is about a 25% decrease in the left ventricular volume, which returns to normal in the postflight period. There is no evidence to indicate that there is any permanent damage to the heart muscle, although invasive studies on animals have shown such changes (see above, under "space biology"). Physiologists are concerned about the concomitant physiological changes that accompany the cardiovascular changes: shifts in fluid compartmentalization, electrolytic imbalance, changes in hormones, concentration of nutrients, and other elements of the homeostatic mechanism. As it is the carrier of all nutrition to the body, dramatic changes in the cardiovascular system are considered very serious.

The Soviets are using extensive exercise regimes during their missions as a potential countermeasure to the effects of cardiovascular deconditioning (Beregovkin et al., 1980). Cosmonauts are scheduled for several hours of programmed exercise each day; extensive use is made of EKG's during the missions; and excellent records of each crew member are kept. Recently, the Soviets have reported plethysmographic measurement to measure blood flow as an experimental clinical procedure.

The Soviets have experimented with the use of lower body negative pressure devices during missions as a means of retaining the blood in the lower extremities. They have designed a suit called the "Chibis" suit to be worn by cosmonauts. These suits have elastic elements that act to retain the blood in the lower extremities (Yegorov and Polyakova, 1983; Yegorov et al., 1984). The Soviet Union also conducts extensive bedrest studies to simulate the effects of extended weightlessness, and have committed human experimental subjects for long periods of time, including the use of cannulation of blood vessels, a procedure that we would not be permitted to do (Lomanov, 1984).

The Soviets are very aware of the US program and have exchanged data freely in this area of research. They frequently cite US workers (e.g., Guyton, Sandler, Stone, et al.) and have participated in a mutual exchange program of bedrest studies and make frequent requests for technical reprints. The Soviets are aware of our university and NIH (National Institutes of Health) efforts in this area.

The Soviets have flown a French cosmonaut, Jean-Laup Cretien, who was an experimentalist with a French/Soviet joint experiment, and, for the first time in space, used an echocardiogram device designed by the French (Beregovkin et al., 1980).

Recently, in collaboration with India, the Soviets performed experiments in which an Indian cosmonaut used a portable vector-cardiograph called the KHAL, developed in India (Pishchik, 1984). In an experiment called "Balkite," they evaluated the force of heart contraction and the coordination of the functioning of right and left heartbeat, using an on-board ballistocardiograph (Faybishenko, 1983).

The Soviets clearly lead the United States in this area of study in space. Generally speaking, cardiovascular physiologists have not been able to evaluate fully the margin of safety of the compensatory return of the cardiovascular system. Neither the United States nor the Soviet Union has yet experienced a fatality or a serious cardiovascular incident. However, the Soviets place great emphasis on studies of this system as part of their long-term mission plans. They are concerned that there may be some irreversible changes from exposure to very long periods of weightlessness that have been overlooked.

## **2. Vestibular Disturbance**

The Soviets are less concerned with the problems associated with space motion sickness than is the United States. In our short-term missions, this affliction presents a problem for up to one-third of the duration of the mission for those astronauts affected. For the Soviets, because of their long-term missions, the practice is to minimize intensive workloads in the early phases of their missions, until the crews' accommodation to the space environment is accomplished. In this way, they have largely avoided the problem rather than solved it.

A significant fraction of both US and Soviet crews have experienced motion sickness during the first few days of spaceflight. From reports by crew members, vestibular physiologists believe that most people are susceptible to this "sickness," but to varying degrees. Symptoms include headache, stomach awareness, cold sweat, pallor, vertigo, illusions, nausea, and vomiting. The extent of difficulty varies with different passengers, and may even vary in the same individual from one mission to another. Most crew

members have associated the illness with rapid movements of the head. By the fifth day in space, all symptoms seem to fade for all individuals and do not recur, although in private communication, the Soviets have reported an occasional recurrence of symptoms late in the flight.

Theories about the cause of space motion sickness have varied over the many years of observation. At one period, a "fluid shift" theory was popular. This idea suggested that the headward accumulation of fluids caused an osmotic change in the vestibular organ which resulted in an imbalance (Yakovleva et al., 1981). Most physiologists today believe in the "sensory conflict" theory, which ascribes the problem to conflicts with the central nervous system from various incoming signals. Information from the eyes, the vestibular organ, the proprioceptor pressure signals, the stretch receptor of the muscles of the head and neck, and the many others that relate to the brain, are all coordinated in the normal individual at one G. When G is removed, the normally strong signal from the otolith (the major gravity-sensing organ) is removed and this results in conflicting signals, thus generating an unresolvable information dilemma in the brain. The symptoms are presumably a classical avoidance behavior of the body toward an unfavorable environment. These same symptoms are seen to varying degrees in fear, food poisoning, gastroenteritis, and pregnancy.

Over the past decade, both Soviet and US scientists have tried a variety of pharmacological agents to control motion sickness in space, but have had only limited success (Shashkov and Sabayev, 1981). Scopolamine is known to suppress the symptoms but results in a reduction of wakefulness. Recently, the Soviets have reported some success with a Hungarian drug known as KAVINTON, (Bodo et al., 1982). They have also tried antihistamines, drugs containing selenium, neuroleptics, and barbituates. Both the Soviets and the United States are expected to continue to test various drugs, but both agree that what is needed is an understanding of the neurophysiological basis of the problem in order to tailor the drug to the problem.

In order to gain such understanding, simulation studies, using rotating and linear moving devices, have been conducted by the Soviet Union (Yakovleva et al., 1981; Kotovskaya et al., 1981). In addition they have used long-term, slow, rotating devices for simulation with extensive testing of subjects. In these studies, no conclusions about the

causes or cures of space motion sickness have been drawn (Galle et al., 1983). Measurements of semicircular canal function, nystagmus, otolith reaction, and vestibular stability are measured. The Soviets have also measured changes in visual perception and have tried to understand the "illusions" reported by several of the cosmonauts.

Recently, the Soviets have been exploring various techniques and devices for suppressing motion sickness. Special headgear, such as neck cuffs and a device called the "Cuban boot," have been tested. Recently, the Soviets have experimented with "optokinosis," a method for studying salt loss that could interfere with the visual and vestibular apparatus (Pokrovskiy, 1984).

Soviet cosmonauts appear to be frequent participants in medical tests and in testing potential countermeasures in space. Their system allows for "trial and error," and quick-look examination of ideas. Soviet cosmonauts also have considerably more time aloft than do the US astronauts and are not as constrained by time lines. The US system of medical experimentation is conducted to a larger extent in ground-based laboratories, under very controlled conditions, and is performed in the presence of trained physiologists.

The exact simulation of weightlessness has not been feasible in the area of motion sickness. Rotation, sleds, and short-term falls in airplanes are inadequate to simulate true weightlessness for sufficient periods of time to enable extensive investigations to take place.

### **3. Bone Demineralization**

"Among the various pathophysiological effects of weightlessness, even during the first years of manned spaceflight, attention was drawn to the increased loss of calcium, phosphorus, and other elements, and also to the lowered content of minerals in the bones." So states a prominent article in a Soviet journal (Volozhin, 1984). This continuous loss of bone mass is measured by x-ray photometry and photon absorptimetry, and is considered as a major hazard associated with long-term spaceflight. The loss of bone mineral mass is believed to lead to loss of strength of the bone. The loss continues throughout the flight for many months, at a rate approaching 0.5% per month. However, it is not known whether the rate of bone loss levels off after some prolonged period. In the 175-day Soviet flight, there apparently had been no diminution in bone mass.

The Soviets have made extensive use of animal models for studying the nature of shifts in mineral and protein metabolism (Volozhin, 1984). Hypokinesia, a form of immobilization that resembles bedrest studies in the human, was used extensively on rats, rabbits, and dogs. The Soviets are very adept at bringing two lines of research together, one dealing with humans and the other dealing with animals (Prokhonchukov et al., 1980). While this is used frequently in the United States in pharmacological testing, development of new surgical techniques, and some behavioral studies, there is a tendency for clinical experimentalists to be cautious about using the results of animals in understanding human responses.

From the Soviet studies on bone demineralization, it was learned that spaceflight and bedrest are similar in their course, and therefore that bedrest is an adequate model for study (Volozhin, 1984). There remains still the mystery of the physiological mechanism behind the loss of bone mass. In normal individuals, calcium is constantly replaced in bone by fresh calcium in the diet. Whether, during spaceflight, old calcium is lost faster, or whether the new calcium is not fixed in place rapidly enough is not known. Experiments with calcium supplements or other nutrients added to the diet, both in bedrest studies and in space, have led to no conclusions or countermeasures.

As stated earlier, the Soviets have reported success in preventing osteoporosis in rats by the use of artificial gravity of one G on their Kosmos flights. They assayed the mineral content of rat tibias and measured the weight and volume of the bones. They also carried out absorptimetry with a bone scanner and a radioisotope (Stupakov, 1981). It was found that artificial gravity prevented the losses seen in a comparable set of unspun animals.

Because bone loss is a problem associated only with very long-term flight, the United States has not placed a large investment in understanding or developing a solution to this problem. The Soviets are approaching this issue with sophistication, and their capabilities in this area should not be underestimated. While the mechanism of calcium loss is still unclear, there are associated changes in the protein matrix of the bone. In some very sophisticated work which demonstrates their biochemical capability, the Soviets reported on changes in the various calcium soluble fractions of the bone, the protein complexes, and discussed possible mechanisms of sialic and hyaluronic acid involvement in the mechanism of calcium binding by the bone organic matrix (Prokhonchukov et al., 1982).

There have been occasional Soviet reports on the value of exercise in suppressing the loss of calcium from the bones, although the main rationale for a heavy exercise regime is to prevent muscle loss and to maintain cardiovascular tone.

#### **4. Muscle Loss**

Changes in muscle mass, muscle tone, and neuromuscular responses have all been reported in postflight analyses; changes in posture during flight have also been observed. In the weightless environment, the muscles do not have the continuous stress which is normal, and under these conditions atrophy begins. Measurements of the changes have been made extensively by both Soviet and US scientists (Kozlovskaya, 1981).

Most dramatic is the loss in the circumference of the legs. Frequently there is loss of several centimeters of girth. These changes are all reversible in short-term missions. More important are the changes in the electrical and physical characteristics of the muscles. These changes vary among individuals but can be as large as 50% of normal. Disturbances in the motor functions in crew members were also major and of long duration. Electromyographic results exceeded the controls by more than twice.

Other results involved postural changes affecting postflight equilibrium, stability, and that affected the general center of gravity of the body. This is observed in the gait and stance of the crew in the period immediately after the flight.

Results with animals show a distinct change in the chemistry of the antigravity muscles during 22-day Kosmos flights. Signs of atrophy and the partial death of muscle fibers were observed due to the hypokinesia (Sinyak, 1978).

The findings in both humans and animals have prompted the Soviets to include a severe exercise regime on extended flights of their cosmonauts. Exercise has thus become a routine part of each cosmonaut's day, lasting between two and three hours, and consisting of a combination of treadmill, ergometer, and isometric exercises. The Soviets are evaluating muscle activity periodically using instruments called MIOKOMP and BRIZ (Tass, 1984).

In the postflight period, the Soviets make use of functional therapy, which includes muscle massage, dosed walking, physical training, balneological, and thermal procedures. Using these techniques, the Soviets cite a "more complete and rapid restoration of functional disorders and impairments developed" (Krupina et al., 1981).

## 5. Radiation

The Soviets are far more concerned with the effects of radiation on biological systems than is the United States. Because of the cumulative nature of radiation injury, the dangers of spaceflight increase with duration of exposure to galactic cosmic rays. Solar activity represents a hazard above that constant value. Inside the earth radiation belts the daily dose of galactic cosmic rays is about 14-15 m rem/day; above the belts, the value is about ten times that. Accepted doses of ionizing radiation for humans are in the range of 5 rem/yr. Thus, there is little likelihood of any significant radiation damage for short-term missions in low earth orbits, but unacceptably high risks for long duration (interplanetary) missions without adequate shielding.

The Soviets have been studying the effects of radiation, the risks involved, and methods of shielding for many years. Standards for radiation have been updated and refined frequently by the Soviets. In a recent paper by Kovalev et al. (1983), a hypothetical interplanetary flight is described. In this model, the cosmonauts use the engines to shadow themselves against radiation and the authors calculate dosages from maximum and minimum solar activity. The flight time used was 1000 days. In further studies, they do trade-off studies with the thickness of shielding needed and probabilistic events, and draw conclusions about how to use shielding. They also examine the success-failure possibilities of the flight, looking at certain radiobiological accidents that range from simple loss of appetite to nausea, vomiting, diarrhea, erythema, scaling of skin, and death. They assume no physiological recovery process. They use their calculations to explore the most effective way to use the mass for shielding.

The Soviets have studied the mutagenic effects of spaceflight radiation on fruit-flies; the effects of ionizing radiation on calcium and phosphorus mineral content of bones; the metabolism of mixed myofibers of skeletal muscle (Volozhin, 1984); the use of

electric fields for shielding biological objects (Ryabova, 1983); the action of heavy ions on various seeds; the development of personal dosimeters; the partial shielding of bone marrow; changes in the flight profile--to list just a few areas that demonstrate that they are earnest about their concerns over radiation and the protection needed.

The Soviets have pointed out that the effects of low levels of chronic radiation in many ways mimic the effects of chronic weightlessness, changes in the cardiovascular system, changes in the nervous system, musculature, and blood cells, and effects on the bone. Therefore, they emphasize that strict dosimetric controls must be developed to sort out the causes of physiological disturbances (Arlashonenko, 1980). This paper points out that the basic network which forms the group of general adaptive responses to prolonged forces of harmful exogenic environmental factors, be it radiation or weightlessness, is the central nervous system. The flow of pathological afferent impulses is to the brain from tissues which have been damaged either by radiation or weightlessness. They believe in the generality of these adaptive responses.

## **6. Psychological Factors**

The Soviets have a considerably larger effort in the study of psychological factors than does the United States, which uses psychology largely as a screening factor during selection and then mostly as support for the maintenance of normal life during the post-flight period. There have been no special psychological studies during US missions, and only a few ground-based research projects in "isolation psychology" have been supported. By contrast, the Soviets have a very extensive program of research. They have established a new field of "space psychology" (Beregovoy et al., 1982), with dozens of authors and many monographs involving several institutes, centers, and universities. They have conducted large conferences, symposia, seminar series, written many books, and sponsored lectures on such topics as "engineering--psychology," "cyclograms for creating rigorous motivational setups," "parachute jumps used as a model of stress," and mechanisms for "dynamic spatiotemporal redistribution of the activation level in different areas of the brain."

The Soviets have performed considerable research in social isolation involving prolonged stays in polar regions (Terelak, 1984), and vividly describe Wenterer's syndrome, which includes depression, hostility, irritability, sleep disorders, loss of interest in work, and diminished intellectual capability. They are very familiar with the problems associated with long-term isolation of groups, the sameness of environment that leads to monotony and boredom, and the customary sources of emotional cues. The Soviets are very concerned about progressive withdrawal of the individual which is affected by problem-solving, social work, sociability, and reflectiveness, and have recorded a great deal of relevant data during their long-term Salyut missions.

The Soviets focus on many external features of design that can affect crew performance, e.g., proper color, degree of illumination, arrangement of living quarters, harmful or unpleasant gases, air conditioning, materials that outgas, and the exchange of simple respiratory diseases (Nefedov and Zaloguyev, 1978).

During the time that the Soviets' missions were relatively short (i.e., three months or less), they had a more benign attitude towards the importance of psychological support for the cosmonauts. Now they regard this as critical for the success of their long-term missions. In a very impressive article, one investigator discusses the change in their view from short-term to long-term missions (Myasnikov, 1983):

According to the results of analysis of flight data, this hypothesis (referring to earlier concerns about difficulty in regaining objective consciousness after periods of daydreaming) was not confirmed during missions lasting up to 63 days (USSR) and 84 days (USA). On the contrary, it was found that man cannot only adapt well to the unique habitat in a spacecraft, but work efficiently in it for a long period of time. Nevertheless, the prospect of extending flight tests made it necessary to take into consideration the above consequences and stimulated a search for measures to prevent them. The results of anechoic chamber tests, for example, revealed that under conditions of prolonged isolation the subjects found occupations for themselves during periods when no work was scheduled; they sang, recited poetry, read, painted, engaged in creative writing and crafts, which the researcher took into consideration when preparing recommendations for organizing the work and rest schedule for cosmonauts. During the spaceflights, there were books, sets of postcards, a chess set available for the crew, concerts were broadcast, and occasionally conversations with their families were organized.

However, sporadic use was made of these recreational resources. Each member of the crew spent his personal time at his own discretion, since there was no specially prepared program for organizing leisure time, nor was there any scientific theoretical substantiation for it.

It was only later on that the idea was discussed of making use of active leisure as a regulator of level of wakefulness, by switching to a different work domain or stimulating contemplative activity in relative isolation and through it as a deliberate influence on both the mental status and fitness.

The new stage in the development of cosmonauts, marked by the long-term functioning in orbit of the Salyut complex was associated with the solution of an exceptionally important problem for space medicine and psychology, that of providing for well-being, good effect and high level of fitness of crew members in the course of missions lasting up to 185 days, with the prospect of successful rehabilitation in the postflight period.

We refer to scheduling a man's life and work in a specific environment which required constantly high intellectual affective tension (chronic stress).

In another paper along these lines, Myasnikov and Kozerenko (1981) go on to say that they cannot count on any special reserve of the individual and that "it was deemed desirable to introduce special-purpose psychoprophylactic and psychocorrective measures into the system of medical support."

Soviet psychological specialists discuss the need of individuals for information and emotional experience, and the problems of emotional satiation. They conclude that the key is in providing the crews with significant information as a means of preventing the psychological effects of deprivation. They have gone to great lengths using onboard and ground-based resources. The Soviets have included tape and videotape recorders, Soviet and foreign movies and state productions. During missions, the on-board videotape library was supplemented with new material by the visiting crews. It included tapes of events about the missions, films of the crew's families, co-workers, and friends. They had entertainment programs prepared by other countries participating in the Interkosmos program. The crews got news, special science, technology, cultural events, sports, and musical background. They heard "functional music"(?) and reproductions of sounds of familiar noises on earth (rain, birds, city noises).

The background music was used constantly and was heard by ground control personnel during their transmissions to earth. "The shortage of social contacts was compensated for by organizing communication sessions with the participation of representatives in areas of public life, political reviewers, sports commentators, artists of the theatre and movies" (Myasnikov and Kozerenko, 1981). The Soviets selected the individuals based on the unique tastes and needs of each of the crew members. In 118 communications during the Salyut missions, they used 100 people.

Soviet specialists also took advantage of the individual creative capability of the cosmonauts by switching work to accommodate personal preference. For this they assembled a wide assortment "of oceanologists, vulcanologists, meteorologists, glaciologists, biologists, astrophysicists, all organized at the Mission Control Center." They obviously had an all-out effort to guarantee that everything was being done to keep the cosmonauts in close link to the earth. They call this "psychoprevention."

Soviet attention to details in this area of psychology, making measurements, conducting experiments, and using psychological support is very impressive.

## **7. Immunology, Blood, and Fluids (Electrolytes)**

Modern techniques of clinical analysis permit extensive chemical and biological examination of blood and other body fluids. Samples have been taken before, during, and after flights by both Soviet and US counterparts. In general, there are no large physiological problems seen that would not have been anticipated. Evidence of stress is exemplified by the presence of certain corticosteroids. Most blood constituents remain in the normal range.

Some changes have been seen in the formed elements (blood cells) by both groups. Red blood cell anomalies are more frequent during flight and in the postflight period. Certain changes in metabolism have been observed but no great physiological importance assigned (Ushakov et al., 1981). There is a shortening of the lifetime of erythrocytes postflight, paralleled by an increase in proliferation of the erythrocytes (Ilyukhin and Burkovskaya, 1980). Some structural changes have been observed in blood cells (Ushakov et al., 1981). The Soviets demonstrated good laboratory capability through the use of electron microscopy and good statistics. Measurements have been made of blood hemoglobin throughout Soviet flights, and these have been compared with the results of

simulation studies using bedrest (Balakhovskiy et al., 1980).

In the area of immunology, both the United States and the Soviet Union have been concerned with possible changes in the immune system as a result of spaceflight. For some time, the Soviets have been following changes in various components of the immune system both in cosmonauts and using experimental flight animals (Ivanov and Shvets, 1979; Guseva and Tashpulatov, 1979; Tashpulatov and Guseva 1979). In these studies they have observed a modest inhibition of immunological reactivity. They also observed an increase in globulin and decrease in albumin, but all blood proteins returned to normal levels postflight. On a recent flight, they observed an increase in lymphocytes--but even this change was within physiological limits (Lesnyak and Tashpulatov, 1981).

What is clear is that the Soviets are not ignoring areas of research even where there are no specific results indicating a problem. They are resolute in their thoroughness, making sure that they have not overlooked any possible hazard.

## **8. Other Biomedical Aspects**

### **a. Nutrition, Diet, and Metabolism**

The Soviets have carried out extensive clinical tests on humans and animals under both simulated and inflight conditions. For their long-term missions, they are very cognizant of possible adverse effects of the absence of gravity that result in hypokinesia, and small changes in the metabolites of the blood; they are careful not only in making measurements during flight, but also in following the crews during their recovery period (Lobova et al., 1984). Their dietary studies have taught them that the conditions of spaceflight, such as hypokinesia, work schedules, and possible exposure to small amounts of toxic gases such as carbon monoxide, have greater effects on metabolism than a particular kind of dehydrated or preserved food that might be used (Bychkov et al., 1979). One of the more significant findings by both the United States and the Soviet Union is the change of secretion by the kidney which is under hormonal control (ACTH). The Soviets relate an increase of ACTH to a concomitant increase in antidiuretic hormone (Noskov et al., 1981). There is still some confusion about the glucocorticoids in weightlessness and the so-called imbalance of this feedback system which regulates kidney function.

#### b. Drugs

The Soviets are enthusiastic about the possible use and development of pharmacological agents for dealing with the clinical manifestations of spaceflight (Shashkov and Sabayev, 1980). They have experimented with a variety of cardiovascular agents, antihypoxic agents, neurological substances, beta blockers, sympatholytic and myotropic substances, and combinations. The Soviet physiologists have had a freer hand in experimenting with the cosmonauts than have their US counterparts, both because of different medical traditions and because of the long time available in orbit of the Soviet missions.

#### c. Measurements

The Soviet long-term missions allow for many kinds of measurements to be made during the mission. They make extensive measurements of changes in body mass (Yegorov et al., 1981), size, blood circulation, skin tone, and a variety of outward clinical manifestations of physiological or emotional stress on each individual.

#### d. Breathing and Respiration

The Biomedical Problems Institute deals also with hypobaric and hyperbaric conditions, and their long-term study of divers has been a fine source of respiratory physiology that has been applied to the space conditions. They have experimented with various atmospheric mixtures, e.g., He-Oxygen (Ogorodnikova, 1979), to explore possible decompression scenarios for use in the cabin or for EVA.

#### e. Infections and Intestinal Flora

The Soviets have performed several thorough studies of respiratory and intestinal organisms. Their largest concern is staphylococci on board the spacecraft. They are particularly worried about "healthy carriers" that may be the source of cross infection and subsequent autoinfection. They have sampled the mouths and noses of crew members and identified the kinds and quantities of organisms on their mucous membranes. Soviet microbiologists have concluded that there is a significant increase in carriers of pathogenic staphylococci (possible sources of infection) during the course of spaceflight. They

used various local antiseptics and antibacterial agents (furacillin, lysozyme) as preventative measures. At the time of this report (Zaloguyev et al., 1981) in 1981, they did not use antibiotics because of the multiple resistance of so many staphylococcal organisms. Similar detailed laboratory work is done on the intestinal microflora (Liz'ko et al., 1979; Goncharova et al., 1981), where it has been shown that changes occur in the quantity of certain kinds of microorganisms of the gut as a result of spaceflight. They ascribe this to "neuroemotional tension."

f. A Broad Array

The Soviets have explored many factors that affect human performance, such as posture, light adaptation (Kartsev, 1981), and circadian rhythms (Myasnikov, 1983). They appear not to wait for a problem to occur but rather prefer to anticipate trouble. By contrast, the United States seems more confident that humans will do fine in space, and that precious man-hours aloft should not be used for physiological experimentation unless there is a known problem (author's opinion).

**D. OPERATIONS**

1. Selection and Training of Crew

Both the United States and the Soviet Union place a great deal of emphasis on the selection and training of crew members, and their respective programs are very similar in many ways. As the complexity of the missions has increased, there is far more emphasis placed on technical education as compared with that of earlier crews, which were made up mostly of experienced test pilots. Now both countries select crew members with higher degrees in engineering, geology, medicine, and physics. The Soviets have an extensive youth program that reaches to a lower age for the beginning of entry into their cosmonaut corps.

The first screening is medical and psychological. Both sides have developed comprehensive histories of the dependability of the system to screen out medical problems. The usual ensemble of medical tests, e.g., cardiovascular, blood tests, neurological, endocrinological, ophthalmological, etc., are routinely carried out on all individuals who are

being considered. These laboratory and clinical exams are performed against a set of values or "norms" that are used as the standards. These tests are updated by both sides as more technology is available and more is understood about the dynamic limits of normal physiology.

It is difficult to say which side places more emphasis on psychological testing. Certainly with their concerns about long-term missions the Soviets have placed this high in their priorities (Gazenko, 1983). The Soviets are very responsive to the most recent psychological evaluation techniques. When assembling a crew for any mission they have an elaborate interactive set of meetings to establish the compatibility of the individuals that will have to work and live together. During the flight, they place great emphasis on continuous high fidelity communication links between the crew and the ground, and frequent exchanges between the crew and family, friends, or celebrities.

The Soviets have, on occasion, claimed that by selection they are able to screen some individuals who have vestibular disturbances and are prone to motion sickness. Based on the small numbers of individuals on both sides who have actually flown, and the scanty records of those who have experienced distress but have not experienced frank symptoms, it is doubtful that we know the answer to the question, "Can we use selection as a means of dealing with motion sickness?"

The training for all cosmonauts is carried out at Star City (one hour from Moscow). The corps includes those who are awaiting flight as well as those who have previously flown. Training includes Salyut flight simulators and two Soyuz simulators and lasts up to two years--depending upon the mission. Both the United States and the Soviet Union have rigorous training programs. One difference that has been cited is that the Soviets do not distribute as much formal documentation, such as their systems manuals; the cosmonauts are expected to develop individual notes which are used as their primary source of information during their missions.

The Soviets have two distinct training programs. One is for their long-term Salyut missions and the other Salyut missions, and the other is for the short-term visiting missions of a week or so. These resident crews are ferried by the Soyuz-T spacecraft (Anonymous, 1981). The Soviets train their cosmonauts with backup crew members for each member of every flight. The United States has backups for the pilot and commander positions, but most of the payload specialists are uniquely trained without backups.

## 2. Operational Medicine: Exercise

For medical management during their flights, the Soviets have developed a large ensemble of physiological tests. They have the capability for performing inflight electrocardiography, electroencephalography, electromyography, thermography, rheography for measuring physical parameters, plethysmography for observing blood flow, and other smaller monitoring devices. They make frequent measurements and have reported this in the open literature.

Both the United States and the Soviet Union have studied the problem of medical care in space. Aside from the most limited first-aid procedures, medical aid is limited to necessity. However, serious problems could arise from accidents or from some somatic diseases. In some cases, return to earth might be possible; in other cases, such a procedure would be deemed impossible. For these, many traditional methods of emergency medicine are not applicable in the special habitat of a spacecraft. General anesthesiological and surgical procedures become extremely difficult. The Soviets are experimenting with a variety of local anesthesia techniques, and have looked into the use of hypothermia for dealing with appendicitis; they have explored temporary soft surgical chambers and the associated problems of vacuuming the body fluids that may be lost under weightless conditions. The Soviets have some advanced ideas about devices for separating gas bubbles from blood, externally to the body, about sorption techniques for detoxification, and the use of blood substitutes.

As a mainstream of their health maintenance, the Soviets employ extensive exercise regimes. For years they have used a treadmill on board and they have experimented with a variety of ergometric patterns using 24-hour days, sometimes 23-hour days, and sometimes 25-hour days. The Soviets have seen small shifts in deep body temperature that are linked to the diurnal circadian rhythms and have even at times selected their crews to be in synchrony. They have also tried both one shift and several shift options.

At present, the Soviets prescribe several hours a day of exercise for their long-term flights, but this can be modified during flight by arrangement between the individual crew member and ground flight surgeons (personal communication). The Soviets claim that the extensive exercise also results in a much easier adjustment upon subsequent return to earth. The postflight adjustment period involves physical exercise,

physiotherapy, and psychotherapy. Upon return to Earth, they take many walks, get muscle massages, therapeutic baths, saunas, swimming, hydro and thermal treatments. They are housed in a sanatorium and resort facility and sometimes in special hospitals. The short US flights require much less formal readjustment.

### 3. Habitability Issues

The Soviets have studied the trade-off of limits to the cabin atmospheric components. An ideal atmosphere, of course, is one bar, but this is very unfavorable for preparing for EVA (extra-vehicular activity). Decompression results when entering the necessary lower pressure of the EVA suit, and this leads to the "bends" (formation of bubbles). The solution is to keep the cabin at a lower pressure in the vicinity of 405mm Hg. Through experimentation, they have found that  $pO_2$  should be kept at 105-125mm Hg and  $pCO_2$  at less than 10mm Hg for optimal balance between the tolerance level of acute hypoxia, the ability to prevent decompression disorders or those due to elevated  $CO_2$  levels (blood acidosis which leads to diminished fitness) (Agadzhanian, 1980). Soviet experience with submarine physiology very likely is carried over into the respiratory studies of the space program.

Sanitation and housekeeping of both US and Soviet vehicles is dealt with as an engineering set of specifications. Temperature, humidity, and air movement are specified. Soviet crew members do not like to sleep in areas where there is little or no air movement (Zaloguyev, 1981). Microorganisms are filtered out of the atmosphere. The Soviets have done substantive studies of confined volumes in which humans shed their microbial load, which then can form aerosols (Pozharskiy, 1984). Their inflight measurements show that, after three months, their system holds the microbial load to under 450 cells per  $m^3$  (Zaloguyev et al., 1984). Personal hygiene is maintained on long-term flights by daily sponge baths and change of undergarments. Wet washcloths are used both after use of their toilet facilities and also at the site of application of medical electrodes. The Soviets state that "knitted fabric underwear absorbed a significant part of the impurities and microorganisms from the skin while it was worn." In general it appears that the Soviets are scrupulous in their concern for hygiene.

#### **4. Food and Nutrition**

Both the US and Soviet programs have learned how important food is in spaceflight. Besides the obvious importance of nutrition, food plays a vital role in the psychological motivation of crews. In the early Soviet missions, food was put up in tubes and cans. As the technology improved, shelf life improved as well as our understanding of dehydration and on-board rehydration with recovery water (Popov, 1981). The Soviets' menu is tailored to the individual tastes of the crew, affording them with considerable variety. The Soviets have observed changes in taste perception during long-duration missions and have added various spices to their foods (Bychko et al., 1980). The average caloric intake is around 3,200 kCal per day. The Salyut has a dining table, food heaters, hot and cold water, and a means for cleaning utensils and disposing of wastes. The meals are treated as a shared banquet. Meals include fresh vegetables, milk, fruits, and preserved meats that are brought by frequent visits of the Progress (unmanned) and Soyuz-T (manned) spacecraft. Cosmonauts have four meals per day, with free time before and after each meal. On this regime, the cosmonauts have maintained their body weights to within five or six percent (sometimes gaining weight). The Soviets report changes in the levels of various digestive enzymes due to the stress of flight and they compensate by adjusting the dietary content.

#### **5. Life Support Systems**

The Soviets use a series of filters to purify the cabin atmosphere; these contain charcoal, fiberglass, and catalytic chemical absorbents. They are experimenting with molecular sieves, zeolite, and supercooling. Oxygen is generated by using oxides and superoxides of alkali metals. The US system now supplies oxygen from liquid oxygen reservoirs and removes the CO<sub>2</sub> with lithium hydroxide absorption. For the long-term missions, the Soviet atmospheric control system is more practical and probably safer.

The Soviets recycle spacecraft cabin water vapor by condensing it on cooling coils. The water then is passed through ion exchange columns, and, after this, through activated charcoal filters. The treated water is sterilized by heating.

The Soviets collect urine and other wastes in tanks, and when filled, they are jettisoned into space. Both the United States and the Soviet Union have programs to examine the recycling of waste products back into food. The Soviet programs in this area have

been discussed above (under Space Biology). For these purposes, the Soviets are also examining the use of artificial soils (Matukovskiy, 1984), which are claimed to be very productive, and have been used on board ocean-going ships where green houses with these soils produce fresh foods. The Soviets connect their space biology with their closed ecological life support studies.

## **6. Extra Vehicular Activity**

Both the United States and the Soviet Union have been successful at developing excellent facilities for performing EVA. The US suit consists of a lower torso garment that is donned, after which an upper torso is pulled over the head, and a helmet affixed on top. Gloves are attached on the sleeves. The Soviets have developed a very unique suit made of one piece. The back is open and the cosmonaut climbs in feet first and then inserts arms and head. Attached to the back are removable cannisters of oxygen and the thermal control mechanisms. The Soviets are very confident in the capability of their EVA suit, as demonstrated by its frequent use during the Salyut missions. The suit has elaborate capability for medical monitoring, EKG, respiratory rate, and pulse rate which are telemetered back to ground medical monitors.

## **E. APPLICATIONS**

Both the United States and the Soviet Union have been keenly interested in the applicability of space technology toward the solution or ameliorization of terrestrial problems. In this regard, over the last half decade, attention has been turned to life sciences issues. Of these, the three major areas being addressed are: 1) the utility of "weightlessness" for the separation of biologically-produced substances (i.e., "bio-processing"); 2) the application of remote sensing techniques to detect, identify, and quantify various compartments of the terrestrial biomass; and, 3) the transfer of technology and information from space medicine to practical clinical medicine on earth.

In the first of these areas, the Soviets appear to have made a strong commitment to the development of instrumentation that could aid in the purification of important biologicals in space. Beginning with their first expedition to Salyut 7, the Soviets performed numerous experiments on this and succeeding expeditions to their space station. In 1982, during their 211-day mission, Berezevov and Lebedev tested a prototype of a future industrial unit, Tavriya, to separate various complex mixtures, cells, and proteins

by electrophoresis (Trud, 1982; Ryumin, 1982). It was claimed that ultrapure biological substances were obtained with a tenfold enhancement in purity, increased rates of separation, and yields up to 100 times higher. In a report summarizing this type of work, Azhitskiy et al. (1984) studied the resolutions obtained by space-borne instrumentation using the techniques of electrophoresis, isoelectric focusing, and isotachopheresis. These studies were continued by Lyakov and Alexandrov during their 150-day mission aboard Salyut 7, and by Kizim, Solov'yev and At'kov during their 237-day mission (Tass, 1984), in which a new, electrophoresis device--the Genom--was used to separate molecular fragments of DNA.

With regard to the second area of applications, the study of agricultural, forest, and marine biota, there is, again, ample evidence of brisk Soviet activity. Since this field has already been briefly alluded to above (Section V.B.3), no further exposition will be made here.

In the third area of applications, the Soviet literature on space medicine (e.g., Alyakrinsky, 1982), as well as many of the relevant public pronouncements, are peppered with references to the utility of the knowledge and technology gained from spaceflight to help combat terrestrial infirmities and ailments. Some examples that have been cited include:

- application of the knowledge gained from medical studies on the effects of weightlessness to treatments for musculoskeletal diseases and diverse types of severe trauma;
- modification of many "shift-type" work schedules in industry, based on experience gained in studies of biological rhythms in space;
- the use of medical telemetry systems derived from space hardware, both for clinical situations and for sports;
- the development of sophisticated techniques, originally intended for medical screening of cosmonauts; for example, methods for detecting latent coronary insufficiencies, reactivity of the vestibular system, and others;
- the development of new agents to prevent motion sickness; and,

- the development of new methods of preparing and preserving food products (cf. also Mal'tsev, 1983; Gazenko, 1983; and Volozhin, 1984).

## F. DISCUSSION

From the foregoing discussion, it should be obvious that the Soviets have a wide-ranging and vigorous program in the life sciences. Furthermore, they do not complicate their philosophical base by trying to satisfy many unrelated goals. Theirs is easily understood and quite clear: the main purpose of Soviet work in the life sciences is to provide optimal conditions for unlimited human space exploration. While they must put emphasis on each immediate, new phase of their overall plan, they nevertheless set themselves very grandiose long-term goals. Officials of the Soviet Union speak often of possible interplanetary missions--particularly to Mars--and even of eventual human colonization of the solar system. With this kind of a "blueprint--however hypothetical--it is easy to fit almost any life science activity into such overall plans.

That this vision is not just pure speculation is attested to by assiduous attention on the part of the Soviets to the potential problems of unlimited human space occupancy. As has been pointed out above, they have truly massive research efforts (by comparison with the United States) in radiation biology, in bioregenerative life support systems, and in artificial gravity. Also, they have a strong interest in psychological problems associated with long-duration missions. It is also obvious that the Soviets are actively studying bone and muscle losses associated with such missions, as well as cardiovascular and other physiological changes--although in these areas, the relative efforts of the United States and the Soviet Union seem to be more-or-less comparable.

It is in the area of "pure science" that the US life sciences work would appear to have a clear advantage over that of the Soviets. Over the past decades, very important new scientific concepts and insights have been derived from US efforts in the space sciences. These have included new ideas about the origin of life; about the interaction of biology and the evolving planet; about the possibility that extraterrestrial events may have had profound effects on the course of biological evolution; and about studying the globe as a total ecosystem. These are just some examples of new ideas spawned by US space activities. No comparable scientific breakthroughs come to the surface in reviewing the Soviet life sciences.

With regard to the future, it seems reasonable to expect that, in keeping with the customary Soviet strategy of incremental growth of capabilities, a new generation of space stations will soon be forthcoming. Indeed, one is apparently in the offing--one that would overshadow their current second-generation Salyut spacecraft, according to a report by Smolders (1984). This next phase is one in which the Soviets would assemble a permanent modular space station of at least 120 tons. The report cites cosmonaut Valeriy Kubasov as claiming that four different modules (one each for astronomy, technology, observations, and biological research) are to be attached to a central core. Later on, according to this report, additional stations would be placed in orbit to form a network around the earth. It is interesting to note the remarks of cosmonaut Grechko, who flew on Soyuz 17 and again on Soyuz 26, in this report:

You already could make a three month (sic) flight, on the condition that you never return to earth. After three years in space (i.e., a possible Mars round trip), you could not return to our planet. Your heart, your entire body, would have adapted to life in space so that you could not stand it on earth. Even after half a year of space travel it is difficult to walk and stand. You sleep poorly, and even eating is unpleasant at the start. After three years, the process is probably irreversible, because there are significant changes during such a flight in your heart, circulatory system, and lungs (Smolders, 1984).

It is small wonder, then, that the Soviets have such an intensive biomedical research program.

## G. CONCLUSIONS

- The Soviets have an announced goal of unlimited manned occupancy of space, and are implementing this goal in an organized step-wise fashion in which each mission builds upon the results of previous ones.
- The Soviets have a considerably larger overall effort in the life sciences than does the United States. They have a trained cosmonaut corps equivalent in size to that of the US astronaut corps, and use payload specialists largely from Eastern Bloc nations, although some have been from Western Europe.
- By contrast with the United States, which has concentrated on short duration manned missions in recent years, the Soviets have incrementally lengthened the mission time of their manned missions up to 237 days.

- The Soviets, thus, have had experience with an operational semi-permanent space station since 1971. It is expected that they will soon launch a new class of modular space stations.
- Major emphasis in the life sciences, in the US and Soviet programs, has been to optimize the performance and health of space crews.
- Both nations have amassed considerable data on human reactions to space flight. There are no significant discrepancies in the respective data obtained by the two countries.
- The Soviets are conducting considerable research on radiation biology (effects, shielding, countermeasures) and on psychological issues--problem areas that might constrain truly long missions.
- The Soviets have also carried out a large number of space experiments on non-human organisms, both on manned and unmanned spacecraft.
- The Soviets regard animal experimentation in space as critical to their ultimate goal of unlimited human spaceflight capability.
- The Soviets have a strong program in artificial gravity, and have conducted experiments both on the ground and in space to test the feasibility of centrifugation as a countermeasure against the effects of weightlessness.
- Both nations have essentially solved the problem of providing adequate life support systems for humans for periods of up to several weeks. For long duration missions in orbit, the Soviets have developed resupply capabilities.
- The Soviets have a strong effort to develop a totally regenerable life support system.
- The Soviet Union is fully capable of performing extended EVA operations on a broad scale.

- Fundamental science goals (in exobiology, gravitational biology, and biospherics) have been more successfully pursued by the United States than by the Soviet Union.
- The Soviets have been vigorously applying space technology to biological problems, such as processing of biological materials in space and using remote sensing techniques.
- The Soviets carry out active collaborative efforts with both Eastern Bloc nations and the West. US collaborative ventures--in the Joint US/USSR Working Group in Medicine and Space Biology and in the Kosmos series of biosatellites--have, on the whole, been very productive.



## CHAPTER V: LIFE SCIENCES

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APPENDIX A

APPENDIX TO CHAPTER II: SOLAR-TERRESTRIAL PHYSICS

Tables A.1 through A.8 list those Soviet spacecraft identified in the literature surveyed for this report.

Table A.1

SOVIET SPACE SCIENCE: MISSIONS KOSMOS

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>	<u>Remarks</u>
Kosmos 184	25 Oct 67	635	635	81.2		meteorology	ion orientation, ionospheric plasma research
Kosmos 348	13 Jun 70	680	212	71	25 Jul 70	geophysics	corpuscular streams, interkosmos program
Kosmos 381	2 Dec 70	1023	985	74		geophysics	top side ionospheric sounder
Kosmos 426	4 Jun 71	2012	394	74		geophysics	charged particles, fluxes, cosmic rays
Kosmos 428	24 Jun 71	271	208	51.7	6 Jul 71	military photo	recovered
P*		239	199	51.7	13 Jul 71	science	x-ray spectrometer
Kosmos 480	25 Mar 72	1212	1183	83		geodetics	
Kosmos 484	6 Apr 72	236	203	81.3	18 Apr 72	military photo	recovered
P*		179	170	81.3	18 Apr 72	science	solar radiation and cosmic ray study
Kosmos 490	17 May 72	310	212	65.4	29 May 72	military photo	recovered

Table A.1 (continued)  
**SOVIET SPACE SCIENCE MISSIONS: KOSMOS**

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>	<u>Remarks</u>
p*		268	202	65.4	6 Jun 72	science	high energy electron flux, cosmic rays
Kosmos 555	25 Apr 73	233	216	81.3	7 May 73	military photo	recovered
p*		222	209	81.3	9 May 73	science	
Kosmos 669	26 Jul 74	244	210	81.3	8 Aug 74	military photo	recovered
p*		225	201	81.3	11 Aug 74	science	
Kosmos 721	26 Mar 75	241	210	81.3	7 Apr 75	military photo	recovered
p*		198	177	81.3	10 Apr 75		
Kosmos 782	25 Nov 75	405	227	62.8	15 Dec 75	biology	recovered
p*		369	216	62.8	10 Feb 76		
Kosmos 900	29 Mar 77	523	460	82.9	11 Oct 79	geophysics	
Kosmos 1067	26 Dec 78	1226	1184	83.0		geodetics	

\* P - Piggyback

Table A.2  
SOVIET SPACE SCIENCE MISSIONS: INTERKOSMOS

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>	<u>Remarks</u>
Interkosmos 2	25 Oct 69	1200	206	48.4	7 Jun 70	geophysics	ionosphere, magnetosphere; E-European cooperation
Interkosmos 3	7 Aug 70	1320	207	49	6 Dec 70	geophysics	study protons, electrons and alpha particles; E-European cooperation
Interkosmos 5	2 Dec 71	1200	205	48.4	7 Apr 72	geophysics	study effects of polar activity on near-earth radiation--cosmic rays, charged particle flux. Soviet-Czech cooperation
Interkosmos 8	30 Nov 72	679	214	71	2 Mar 73	geophysics	study ions, electrons, protons of high energy
Interkosmos 9	19 Apr 73	1551	202	48.5	15 Oct 73	geophysics	Copernicus 500; solar radiation and ionosphere measurements
Interkosmos 13	27 Mar 75	1714	296	83	2 Sep 80	geophysics	upper atmosphere, magnetosphere and polar ionosphere
Interkosmos 14	11 Dec 75	1707	345	74	27 Feb 83	geophysics	
Interkosmos 17	24 Sep 77	519	468	83	8 Nov 79	geophysics	study upper atmosphere and magnetosphere
Interkosmos 19	27 Feb 79	996	502	74		geophysics	study ionosphere, radio propagation
Interkosmos 22	7 Aug 81	890	795	81.2		geophysics	Bulgaria 1300; Ionospheric, magnetospheric research

Table A.3  
SOVIET SPACE SCIENCE MISSIONS: PROGNOZ

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>	<u>Remarks</u>
Prognoz 1	14 Apr 72	200,000	950	65		geophysics	solar wind and magnetosphere
Prognoz 2	29 Jun 72	200,000	550	65		geophysics	
Prognoz 3	15 Feb 73	200,000	590	65		geophysics	interaction of solar wind and earth's magnetosphere
Prognoz 4	22 Dec 75	199,000	634	65		geophysics	solar wind and magnetosphere
Prognoz 5	25 Nov 76	199,000	510	65		geophysics	solar wind and magnetosphere
Prognoz 6	22 Sep 77	197,900	498	65		geophysics	solar wind and magnetosphere
Prognoz 7	30 Oct 78	202,965	483	65	22 Oct 80	geophysics	solar wind and magnetosphere
Prognoz 8	25 Dec 80	199,000	550	65		geophysics	solar wind and magnetosphere
Prognoz 9*	1 Jul 83	720,000	380	65		astronomy	
Prognoz 10* (Intershock)	26 Apr 85	200,000	400	65		geophysics	

\* No literature citations as of 6/85.

**Table A.4**  
**SOVIET SPACE SCIENCE MISSIONS: OREOL**

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Weight (kg)</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Mission</u>	<u>Remarks</u>
Oreol 1	27 Dec 71	630	2500	410	74	geophysics	study upper atmosphere USSR/France
Oreol 2	26 Dec 73	680	1995	407	74	geophysics	scientific payload; USSR/France
Oreol 3	21 Sep 81	1000	1913	399	82.5	geophysics	magnetospheric and ionospheric explorer; USSR/France

Table A.5

SOVIET SPACE SCIENCE MISSIONS: ELEKTRON

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Weight (kg)</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>	<u>Remarks</u>
Elektron 1	30 Jan 64	329	7100	406	61		geophysics	study inner Van Allen radiation belt
Elektron 2		444	68,200	460	61		geophysics	Study outer Van Allen radiation belt
Elektron 3	10 Jul 64	350	7040	405	60.9		geophysics	to monitor inner Van Allen radiation belt
Elektron 4		444	66,235	459	60.9	12 Oct 83	geophysics	to study outer magnetosphere

Table A.6

SOVIET SPACE SCIENCE MISSIONS: MOLNIYA AND RADUGA

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Weight (kg)</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>
Molniya 1-1	23 Apr 65	1750	39,306	731	65.5	16 Aug 79	communications
Molniya 2-1	24 Nov 71	1800	39,553	516	65.0	10 May 76	communications
Raduga 1	22 Dec 75	2500	35,847	35,733	1.4		communications

Table A.7  
SOVIET SPACE SCIENCE MISSIONS: SALYUT

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Weight (kg)</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>
Salyut 6	29 Sep 77	18,900	360	345	51.6	29 Jul 82	space station
Salyut 7	19 Apr 82	17,818	364	360	51.6		space station

Table A.8

SOVIET SPACE SCIENCE MISSIONS: PROTON

<u>Spacecraft</u>	<u>Launch Date</u>	<u>Weight (kg)</u>	<u>Apogee (km)</u>	<u>Perigee (km)</u>	<u>Inclination</u>	<u>Decay Date</u>	<u>Mission</u>	<u>Remarks</u>
Proton 1	16 Jul 65	12,200	627	190	63.5	11 Oct 65	cosmic ray	physics "lab"
Proton 2	2 Nov 65	12,200	637	191	63.5	6 Feb 66	cosmic ray	complex high energy physics laboratory
Proton 3	6 Jul 66	12,200	630	190	63.5	16 Sep 66	cosmic ray	
Proton 4	16 Nov 68	17,000	495	255	51.5	24 Jul 69	cosmic ray	



**APPENDIX B**  
**GLOSSARY OF ACRONYMS/ABBREVIATIONS**

AIAA	American Institute of Aeronautics and Astronautics
AKR	auroral kilometric radiation
AMPTE/CCE	Active Magnetosphere Particle Tracer Explorers/Charge Composition Explorer
AFGL	Air Force Geophysics Laboratory
AXAF	Advanced X-Ray Astronomy Facility
CCD	charged coupled device
Cir	Circinus
COSPAR	Committee on Space Research
Cyg	Cygnus
DESY	Deutsches Elektronen-Synchrotron Laboratory
DNA	deoxyribonucleic acid
DP	descent platform
DSN	Deep Space Network (of large antennas that track spacecraft--NASA)
ESA	European Space Agency
EVA	extra vehicular activity
G	gravity (e.g., zero G, one G)
GRO	Gamma-Ray Observatory
HEAO	high-energy astronomical laboratory
Her	Hercules
HF	high frequency
IAU	International Astronomical Union
ICSU	International Council of Scientific Unions
IR	infrared
IRAS	Infrared Astronomical Satellite
IUE	International Ultraviolet Explorer

L	lander
LMC	Large Magellanic Cloud
MSIS	Mass Spectrometer/Incoherent Scatter
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NOAA	National Oceanic and Atmospheric Administration
O	orbiter
OAO	orbiting astronomical observatory
OSO	orbiting solar observatory
P	pressure
PVO	Pioneer Venus Orbiter
RNA	ribonucleic acid
SAS	small astronomical satellite
Sco	Scorpius
SETI	search for extraterrestrial intelligence
SIRTF	Space Infrared Telescope
SSB	Space Science Board
SSEC	Solar System Exploration Committee
STP	solar-terrestrial physics
T	temperature
UHF	ultra-high frequency
URSI	International Radio Science Union (France)
UV	ultraviolet

V	visible
VLA	very large array
VLBA	very long baseline array
VLBI	very long baseline interferometry
VLF	very low frequency



## APPENDIX C

### ABOUT THE AUTHORS

**Louis J. Lanzerotti.** Dr. Lanzerotti received his undergraduate degree at the University of Illinois and his AM and PhD degrees at Harvard University in 1963 and 1965, respectively. He has been involved in space physics research since he joined AT&T Bell Laboratories in 1965. He has been a Visiting Astronomer at Kitt Peak National Observatory and a Visiting Professor at the University of Calgary. He is presently an Adjunct Professor at the University of Florida. Dr. Lanzerotti's principal research interests include studies of planetary magnetospheres, energetic particles emitted by the sun, and the impacts of geomagnetospheric processes on space and terrestrial technologies. He has published extensively in the field and is co-author or co-editor of three books. A Fellow of the American Physical Society, the American Association for the Advancement of Science, and the American Geophysical Union, he has served on numerous NASA and National Science Foundation committees concerned with space and solar-terrestrial research as well as on advisory boards for geophysical institutes in the United States and Europe. He is presently the US representative to the Upper Atmosphere Physics Working Group of the Scientific Committee on Antarctic Research, the Chairman of NASA's Space and Earth Science Advisory Committee, and a member of the NASA Advisory Council.

**Richard C. Henry.** Dr. Henry is a Professor in the Department of Physics and Astronomy at The Johns Hopkins University and a former (1976-1978) Deputy Director of the Astrophysics Division of the National Aeronautics and Space Administration (NASA). He is a past Alfred P. Sloan Foundation Fellow. He was graduated from Ridley College in 1957; obtained a BSc and an MA at the University College, University of Toronto, where he won the Royal Astronomical Society of Canada Gold Medal; and was awarded a PhD by Princeton University in 1967. Dr. Henry has been a research associate at the Institute for Advanced Study, a research physicist at the US Naval Research Laboratory (NRL), and a lecturer at the Latin American School of Space Research in Argentina. He has conducted astronomical investigations at the Kitt Peak National Observatory in Arizona, Cerro Tololo Interamerican Observatory in Chile, and has participated in many rocket-astronomy experiments. He has made observations using the Copernicus and IUE satellites and also the Mariner 9 spacecraft to Mars; he was a co-investigator on Apollo 17 and on the Apollo-Soyuz mission; and he is co-investigator on the UVX and Hopkins Ultraviolet Telescope Space Shuttle experiments. He was a principal investigator in the study of lunar material; has participated in eclipse expeditions in Quebec (1972), India (1980), and East Africa (1973, 1981); and was a member of the group which discovered the first x-ray pulsar. Dr. Henry has published more than 90 research papers in theoretical astrophysics, observational astronomy, radio astronomy, ultraviolet astronomy, and x-ray astronomy.

**Harold P. Klein.** Dr. Klein was Director of Life Sciences at NASA's Ames Research Center until his retirement in May 1984, where he was responsible for research and development activities ranging from research on the origin and distribution of life to biomedical research and aviation safety. He is now at the University of Santa Clara. He received a BA in Chemistry from Brooklyn College in 1942 and a PhD in Bacteriology

from the University of California in 1950. A specialist in microbial physiology, Dr. Klein joined Ames in 1963 following seven years as Professor and Chairman of the Biology Department at Brandeis University. He has also taught at the University of California at Berkeley and at the University of Washington Medical School. He has published more than 130 technical papers in the areas of microbial biochemistry, space biology, and exobiology; he was leader of the Viking biology team which performed automated life detection experiments on Mars (1976-1977); and he has flown biological experiments on two Soviet space missions (1977, 1979). In 1977, he received the NASA Medal for Outstanding Leadership and was also the recipient of a Presidential Meritorious Service Award. He has served on several advisory committees to NASA and was a member of the Joint US/USSR Working Group in Space Medicine and Biology from its inception in 1971. He is an editor of the journal, Origins of Life, and referees papers for other journals, including Science, Icarus, Plant Physiology, and Journal of Molecular Evolution.

**Harold Masursky.** Mr. Masursky received a BS in Geology and Civil Engineering (1943) and an MS in Geology (1950) from Yale University. For his continuing outstanding contributions to science, in 1981 he was awarded the degree of Doctor of Science from Northern Arizona University (Flagstaff). He joined the US Geological Survey in 1947 as a general geologist, studying uranium-bearing coal deposits in Wyoming and gold deposits in Nevada, working on the state geologic map of Montana south of Glacier Park, and doing detailed mapping northwest of Yellowstone Park. In 1972, he joined the newly-formed Branch of Astrogeologic Studies of the US Geological Survey, whose mission was to study the moon and planets in support of the US space program. Since joining this group, Mr. Masursky has played a leading role in almost every facet of lunar and planetary exploration. He has been an experimenter on nearly every NASA flight program for the moon and planets; has served on numerous NASA, National Academy of Sciences (NAS), and international advisory groups; was a member of joint US/USSR and US/European Space Agency (ESA) Planetary Exploration Working Groups; and is presently working on the Voyager mission to Jupiter, Saturn, Uranus, and Neptune, on the Galileo Mission to Jupiter, and the Venus Radar Mapper Mission. In recognition for his contributions to the US space program, he has been awarded NASA Medals for Exceptional Scientific Achievement on four separate occasions (in 1972 for his work on Apollo 15, 16, and 17, and for his work as leader of the Mariner 9 imaging team; in 1977 for his role as leader of the Viking site certification team; and in 1980 for his work on the Venus Pioneer Orbiter radar team). He has been President of the Planetary Division of the Geological Society of America, President of the Working Group for Planetary System Nomenclature, International Astronomical Union, and Vice President of the Committee on Space Research (Committee B).

**George A. Paulikas.** Dr. Paulikas has been Vice President of the Laboratory Operations of The Aerospace Corporation since 1981, having previously (1968-1981) served as the Director of the Space Sciences Laboratory. He received a BS in Engineering Physics (1957) and an MS in Physics (1958) from the University of Illinois and completed a PhD in Physics at the University of California at Berkeley in 1961. His research interests include atomic physics, plasma physics, and space science. He has published extensively in the field of magnetospheric physics and received The Aerospace Corporation Trustees' Distinguished Achievement Award in 1981 for his work in this field. Dr. Paulikas is a

Fellow of the American Physical Society, a member of the American Geophysical Union, Sigma Xi, and an associate fellow of the American Institute for Aeronautics and Astronautics (AIAA). He has served as Associate Editor of the Journal of Geophysical Research, participated in several National Academy of Sciences (NAS) studies, has served on the NAS/Space Science Advisory Board and as a consultant to NASA. He has also served as Chairman of the AIAA Committee on Space Science and Astronomy, was a consultant to the Lawrence Berkeley Laboratory, a member of the University of California Advisory Council on Geophysics, and a member of the Executive Council of the University of California (Berkeley) Space Sciences Laboratory. Dr. Paulikas presently serves on the Los Alamos National Laboratory Physics Division Advisory Committee.

**Frederick L. Scarf.** Dr. Scarf is presently Chief Scientist for Space Research and Technology in the Applied Technology Division of the TRW Space Technology Group. He received a BS in Physics from Temple University in 1951 and a PhD in Theoretical Physics from the Massachusetts Institute of Technology (MIT) in 1955. He has served as a research associate at MIT and as Assistant and Associate Professor of Physics at the University of Washington. Since joining TRW in 1962 as a member of the technical staff, he has managed the Space Physics Analysis Department and the Space Science Department. His extensive research activities are primarily in the field of space plasma physics, and he is presently Principal Investigator for the plasma wave investigations on the operational spacecraft, Voyager 1 and 2, Pioneer Venus Orbiter, ISEE 3, and Pioneer 8 and 9; he is Lead Investigator for the AMPTE/CCE plasma wave instrument and co-investigator for corresponding wave instruments in Galileo, ISEE 1 and 2. Dr. Scarf is also a Galileo Interdisciplinary Scientist and is the co-investigator responsible for providing US wave instrumentation on the Japanese Geotail spacecraft that will be part of the International Solar-Terrestrial Physics Program. In the past, he has served as principal investigator for wave instruments on OGO-5, IMP-7, and several US Air Force spacecraft. For six years, Dr. Scarf was Chairman of the National Academy of Sciences (NAS) Panel on the International Magnetospheric Study, and he has been a member of the NAS Space Science Board and the NASA Space and Earth Science Advisory Committee. He has also served on the NAS Committees on Space Physics and Solar-Terrestrial Research, as well as the ICSU Special Committee on Solar-Terrestrial Physics (SCOSTP). He has been International Vice Chairman and Chairman of the URSI Commission IV (on the Magnetosphere); a member of the US National Committee for URSI (National Academy of Sciences) and a member of its Executive Committee; a member of the NAS/SSB Joint (US/European) Working Group on Planetary Exploration and Chairman of its Outer Planets Study Team. Dr. Scarf is presently a member of NASA's Solar System Exploration Committee and its Solar System Exploration Management Council. He was recently appointed as a member of the Steering Committee and as Chairman of the Solar and Space Physics Task Group for the NAS/Space Science Board Study, "Major Directions for Space Science: 1995-2015." He is the author or co-author of more than 220 scientific publications, and in 1981, Dr. Scarf received NASA's Exceptional Scientific Achievement Medal.

**Gerald A. Soffen.** Dr. Soffen is currently Associate Director of Space and Earth Sciences at NASA's Goddard Space Flight Center. He received a BA from the University of California at Los Angeles in 1949, an MS from the University of Southern California in 1956, and a PhD in Biology from Princeton University in 1960. Prior to his coming to Goddard, Dr. Soffen was the Director of Life Sciences at NASA Headquarters in Washington, DC, and was responsible for the medical care of the astronauts, the Biomedical Program, the Space Biology Program, and the Exobiology Program. His division planned and directed the work of numerous efforts carried out in the Ames Research Center, the Johnson Space Center, and the Jet Propulsion Laboratory. Before his assignment to NASA Headquarters, he was the Chief Environmental Scientist at NASA's Langley Research Center in Hampton, VA, where his work included theoretical models, laboratory experiments, ground-based measurements, and remote sensing by satellite. This required coordinating environmental problems involving several Federal agencies, universities, and other institutions. Dr. Soffen was the Project Scientist for the Viking Missions to Mars, which was launched in 1975 to conduct scientific investigations from orbit, during entry, and on the Martian surface. The Vikings were the first successful missions to perform unmanned experiments on the surface of the planet. Dr. Soffen was responsible for all of the scientific investigations, directing the activities of over 70 scientists throughout the United States. He was Chairman of the Science Steering Group and Principal Scientific Advisor to the Project Manager. Prior to the Viking Project, he managed biological instrument development at the Jet Propulsion Laboratory in Pasadena, CA.

**Yervant Terzian.** Dr. Terzian is Professor of Astronomy and Space Sciences and Chairman of the Department of Astronomy at Cornell University, where he is a recent recipient of the Clark Award for Distinguished Teaching. He received a BSc in Physics and Mathematics from the American University, Cairo, in 1960, and an MS (1963) and a PhD in Astronomy (1965) from Indiana University. His field of expertise is the physics of the interstellar medium of our galaxy and other galaxies. He has also made many contributions to the late stages of stellar evolution, particularly in the study of the ejected material from dying stars. He has worked extensively with radio telescopes around the world, including the 100-meter radio telescope of the Max-Planck Institute in Germany, the US Very Large Array, and the 1000-ft Arecibo radio/radar telescope. He has been associated with the Arecibo Observatory in Puerto Rico (operated by Cornell University for the National Science Foundation) for more than twenty years. Dr. Terzian has been Visiting Professor at many universities around the world, including the University of Montreal (Canada), the University of Thessaloniki (Greece), and the University of Florence (Italy). He has served as Chairman of numerous national and international scientific committees affiliated with NASA, the US National Academy of Sciences, and the International Astronomical Union, among others. He has been President of Cornell's Sigma Xi Scientific Research Society, and has been Chairman of several Cornell faculty committees, including the Research Policies Committee. Among graduate courses, he also teaches a popular undergraduate course in astronomy. He is the author or co-author of more than 120 scientific publications and is the editor of four books.

**APPENDIX D**  
**FASAC REPORT TITLES**  
(completed)

**FY82-83**      Soviet High-Pressure Physics Research (FASAC-TAR-1017)  
Soviet High-Strength Structural Materials (FASAC-TAR-1018)  
Soviet Applied Discrete Mathematics (FASAC-TAR-1019)  
Soviet Fast-Reaction Chemistry (FASAC-TAR-1020)

**FY-84**      Soviet Physical Oceanography Research (FASAC-TAR-2010)  
Soviet Computer Science Research (FASAC-TAR-2020)  
Soviet Applied Mathematics Research: Mathematical Theory of Systems,  
Control, and Statistical Signal Processing (FASAC-TAR-2030)  
Selected Soviet Microelectronics Research Topics (FASAC-TAR-2040)  
Soviet Microelectronics (Pulsed Power) Research (FASAC-TAR-2050)

**FY-85**      FASAC Integration Report: Selected Aspects of Soviet Applied Science  
Soviet Research on Robotics and Related Research on Artificial  
Intelligence (FASAC-TAR-3010)  
Soviet Applied Mathematics Research: Electromagnetic Scattering  
(FASAC TAR-3020)  
Soviet Low-Energy (Tunable) Lasers Research (FASAC-TAR-3030)  
Soviet Heterogeneous Catalysis Research (FASAC TAR-3040)  
Soviet Science and Technology Education (FASAC-TAR-3050)  
Soviet Space Science Research (FASAC-TAR-3060)  
Soviet Tribology Research (FASAC-TAR-3070)

(in production)

**FY-85**      Japanese Applied Mathematics Research: Electromagnetic Scattering  
Soviet Spacecraft Engineering Research  
Soviet Low Energy Combustion Research  
Soviet Exoatmospheric Particle Beam Research  
Soviet Research in Remote Sensing of the Land and Atmosphere  
Soviet Research in Fracture Mechanics

