Chapter 9

SPACE SCIENCE

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INTRODUCTION

A substantial part of the research activity carried out in space is directed, not at the achievement of economic benefits and commercial applications, but at the purely scientific study of phenomena in and from space. This broad field of endeavor, known as space science, began to develop many years before the advent of orbiting satellites; from the 1940s on, scientists used sou riding rockets and balloons to loft instruments and animals above most of the insulating and protective blanket of atmosphere to acquire data about the space environment. These studies contributed to an ever-increasing body of knowledge about outer space. By contrast, over the past quarter-century, Earth-orbiting and interplanetary spacecraft have been the catalyst for an explosive growth of knowledge in this field.

The rapid expansion of space science has produced a number of component disciplines and subdiscipline. For organizational purposes, the National Aeronautics and Space Administration (NASA), which funds most space science research, divides space science into three areas: 1) physics and astronomy, 2) planetary exploration, and 3) life sciences.

- **Physics and astronomy** encompasses the study of the structure and dynamics of the Sun, solar-generated phenomena such as the solar wind, and other features of the near-Earth interplanetary environment such as the magnetosphere and incident cosmic rays. Also included in this area are some of the most compelling and exciting investigations in any scientific field: the study of astronomical objects by means of telescopes and other space-borne instruments. These objects include not only our own Sun and the multitude of stars and other condensed objects of the Milky Way Galaxy, but also the gas and dust between these stars, and finally the vast swarm of galaxies extending out to the edge of the visible universe.

  Observations from space take advantage of the entire spectrum of electromagnetic radiation to acquire much more extensive data on large- and small-scale cosmic processes than can be taken from the ground, where only optical and radio wavelengths are received. Access to all regions of the spectrum as well as the removal of atmospheric distortion has produced, in the span of a few years, a major revolution in our understanding of the nature, origin, and evolution of the universe and its component matter.

Photo credit: National Aeronautics and Space Administration

X-ray image from NASA's High Energy Astronomy Observatory (H EAO-2) of remnant of exploding supernova in the constellation Cassiopeia. Scientists estimate that the star from which this cloud of expanding hot gas derives originally exploded in A.D. 1657.

- **Planetary exploration is the study of the planets of our solar system and their satellites, the asteroids, and the comets. Activities in this area include the dramatic unmanned exploratory missions to the surface or environs of other planets, and the manned lunar landings. investigations of the surface features and (if possi-**ble) composition are made along with studies of the planetary atmosphere and magnetosphere, if they are present. These observations are combined with data regarding orbital mechanics and rotational characteristics to provide an understanding of the planet's internal composition and dynamics, and thus its origin and evolution.

- Life sciences are generally subdivided into biomedical research (the study of the effect of space environmental factors on man) and space biology (the effect of these factors on plants and animals). Separate but related areas are planetary biology, the study of the origin and distribution of life in the universe, and global biology, which examines the impact of life on our own planetary environment. important areas of research are the effects of prolonged exposure to microgravity and ionizing radiation on humans and animals, and the study of plant developmental processes in space under artificial lighting. One objective of the latter research is the development of advanced life support systems. Because of the difficulties associated with supporting life in space, ground-based simulation studies are especially important in the space life sciences.

Although research in each of these areas produces results that have great intrinsic value in adding to our understanding of the cosmos and our place within it, this research is not pursued solely for its own sake. Space science provides much of the research base that underlies the development of applications-oriented programs discussed in earlier chapters. The subdiscipline of solar-terrestrial physics, for example, forms a direct bridge between solar research (physics and astronomy program) and Earth applications such as communications, navigation, and meteorology. Studies of planetary magnetic fields, magnetospheres, and ionospheres have a direct relevance to corresponding research in Earth's plasma envelope and upper atmosphere.

In the long term, planetary studies also offer the possibility of habitation and minerals exploitation. Life sciences research offers a wealth of potential applications, from the prolongation of human stay-times in space, to the pursuit of space agriculture and partly closed life support, to the development of new medical treatments, diagnostic techniques, and devices. Instruments and sensors developed in every area of space science eventually find their way into commercial application. Thus, programs in space science are a necessary basis for any nation's activity in space. **Nations that wish to pursue practical or commercial activities in space on their own must first either pursue a program of space science themselves, or have access to the technology and basic data that emerge from the conduct of such a program.**

Cooperative Ventures in Space Science: The Opportunity and the Challenge

As was discussed in chapter 3, the United States has engaged in a vigorous program of international cooperative ventures in space. When all forms of joint activity are taken into account, NASA alone has concluded over 800 agreements with over 100 countries.[1]

From the standpoint of individual projects, the most notable single area of U.S. international space cooperation has been the space sciences.[2] It was apparent from the beginning that cooperation in this field offered many advantages, from the point of view of both the United States (the leader and principal in these ventures) and the cooperating nations. On the technical and political level, the appeal of multinational space science stems from the global sphere of operations of satellites, and from the global and universal perspective necessitated by operations in space.

More practically, the enormous cost of pursuing space science has been a strong argument for sharing the economic burden among as many nations as efficiency permitted. In effect, if NASA does not have enough money to pursue a project alone, by cooperating with other countries it may actually create opportunities to undertake research it could not otherwise have done. The pooling of scientific and technical talent offered another strong advantage, and was allied with the

[1] *25 Years of NASA International Programs,* NASA report, January 1983.

[2] *UNISPACE '82:* A Context *for International Cooperation and Competition–A Technical Memorandum* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-26, March 1983), p. 68.

value to the United States of building scientific/technical strength among its allies. These advantages were not restricted to the United States and its partners, but applied as well to the Soviet Union–the other leading nation in the early decades of space activity—in its dealings with its client states and a few other nations through the Intercosmos program.

Now, as technical capability for the independent conduct of space science has spread to the European Space Agency (ESA) and many of its member nations, to Japan, and potentially to some developing countries, the benefits of cooperation are coming into play for a wider range of nations.

Conversely, the *disadvantages* of joint pursuit of science in space are also being felt more widely and perhaps more acutely. Prominent among these are the problems attendant upon planning for and conducting long-term joint development activities, during which any number of economic and national policy imperatives may intervene to disrupt schedules and commitments. Differences in managerial style, and the difficulties in achieving satisfactory management of parallel development programs, produce another set of problems.

As cooperative partners in space sciences are increasingly likely to be competitors in other scientific or industrial fields (or even in other areas of space activity), the issue of technology transfer is becoming a matter of increasing concern. This is especially true in light of the possibility that cooperative ventures may entail lost opportunities for indigenous scientists and indigenous technology development.

Competition in Space Science: The Shifting Balance

The First 15 Years

After World War II, one of the crucial factors setting the stage for the "space race" of the 1960s was the fact that most of the expatriated European scientists and engineers came to the United States, while the Soviet Union acquired the bulk of the surviving German V-1 and V-2 rockets (along with some technicians and engineers). The influx of talent on the one hand and hardware on the other probably led to the development, throughout the 1950s, of a broader based expertise in the essential space technologies in the United States, contrasted with an accelerated launcher capability in the U.S.S.R. The surprise launching of Sputnik in 1957 galvanized the latent capabilities of the American space community into focusing on achievement and dominance in space.

The emphasis on manned spaceflight throughout the 1960s, culminating in lunar landing and exploration, obscured (and to some extent impeded) developments in space science. Although the lunar missions were certainly "planetary," science was secondary to the engineering accomplishments involved. Yet from the beginning of both programs the science return was impressive.

The U.S.S.R. led initially. The second Sputnik, launched a month after the first, carried substantial geophysical and radiation-sensing instrumentation as well as a life support system and biomedical instrumentation for monitoring the effects of spaceflight environmental factors on its live payload, a dog. The third Soviet satellite, launched shortly after the first two American successes, was a 1 %-ton orbiting geophysical laboratory. By late 1959, the U.S.S.R. had struck the Moon (Luna 2) and photographed its far side (Luna 3). In 1961 the manned orbital missions began, with a return of important biomedical data.

Soviet planetary satellites launched before the end of that year had already provided data on solar and cosmic radiation across the electromagnetic spectrum and on the upper atmosphere. However, between 1960 and 1965 a total of 18 planetary missions to Venus and Mars failed to return any planetary data, primarily because of contamination problems.[3]

The American space science effort got off to a slower start, but had a higher success rate. Significant data were returned by the second Mariner mission to Venus, in 1962. Likewise, the second mission to Mars, in 1964, provided pictures

[3] *Soviet Space Programs, 1966-70,* **Congressional Research Service, Science and Technology Division, 1971, p. 166.**

and data. However, a long series of Pioneer missions to the Moon, beginning in 1958, was unsuccessful. Not until 1964, with the Ranger series of TV-equipped hard landings, were U.S. lunar missions fruitful. Meanwhile, the Explorer series of Earth and space science satellites was highly successful. Explorer 1, for example, discovered the existence of ionized particles trapped in Earth's magnetic field (the so-called Van Allen radiation belts); subsequent Explorer missions paralleled the Soviet program in space science.

In manned spaceflight, Project Mercury lagged its Soviet counterpart: the first U.S. orbital flight did not occur until considerably after the second Soviet orbital mission had taken place. Not until the advent of Gemini in 1965 did the U.S. program gain momentum and surpass (perhaps in late 1966) the Soviet effort. The Soviets later regained this lead in the mid-l970s, as the U.S. Skylab program was concluded and the Salyut program got fully under way.

Dynamics of Competition

Despite the size of the U.S. investment in the manned program during its first decade, the science return was relatively small. Like its Soviet counterpart, its primary aim was national prestige, not science. In the post-Apollo era, however, the U.S. manned program has been more careful to build in significant science components from the beginning planning stages of its missions. The U.S. space science program also came into its own in the 1970s, highlighted by the Viking missions to Mars and the launch of the Voyager spacecraft to the outer planets. The mid-1970s saw funding peaks for space science missions, but these were followed by drastic budget reductions later in the decade.[4] Meanwhile, the Soviet Union established a dominant position in manned orbital operations through the series of Salyut space stations. The continuity of the Salyut program exemplifies the pattern of U.S.-Soviet competition in all space activities, including space science: the Soviets are able to sustain a steady, long-term commitment in any area of space activity they view as supportive of their long-term goals; the U.S. program, being subject to the annual congressional budget process, is more likely to undergo short-term perturbations.[5] Thus, although the U.S. space science missions were more sophisticated than were those of the Soviets, Soviet space science capabilities continued to grow, particularly with the increasing use of Salyut as a platform for research[6]

The strong position of power occupied by the U.S.S.R. Academy of Sciences ensures that basic science will not be ignored.[7] The fact that the U.S.S.R. is sending a mission to Halley, that it is continuing to conduct missions to Venus, and that it plans a flyby of the Martian Moon Phobos in 1988, is strong evidence of its continuing interest in science. However, Soviet space activities in recent years have in general become in-

[4] *Space Science Research in the United States—A Technical Memorandum* **(Washington, DC: U.S. Congress, Office of Technology Assessment,** OTA-TM-STI-19, **September 1982), p. 41.**

[5] *Salyut: Soviet Steps Toward Permanent Human Presence in Space–A Technical Memorandum* **(Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-TM-STI-14, December 1983), p. 3.**

[6] Alain Dupas, "Un **Programme Spatial en** Plein Renouveau," ***La*** *Recherche*, **November 1984, pp. 1420-1427.**

[7] *Soviet Space Programs: 1976-80* **(Part I), Congressional Research Service, December 1982,** p. **157.**

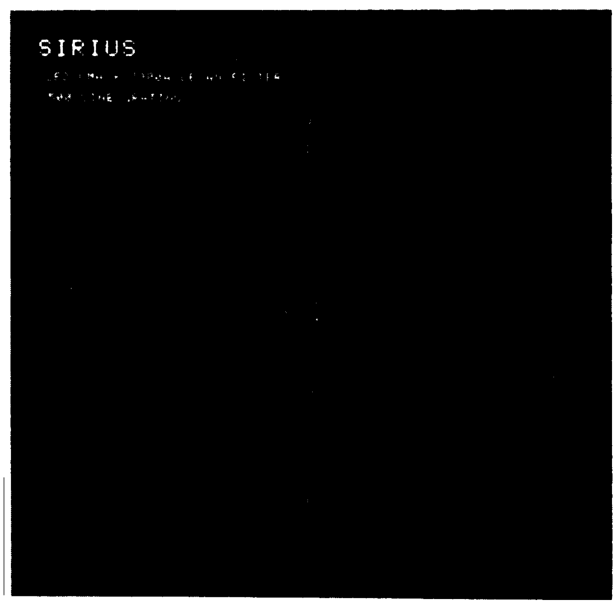

Photo credit: European Space Agency

Spectra of Sirius A, the brightest star in the sky, and of Sirius B, its white dwarf companion. The X-ray spectrum of the white dwarf is the vertical line. The first and second order ultra-violet spectra of Sirius A are along the horizontal.

creasingly applications-oriented, and the flight of large-scale, advanced-technology U.S. and European space observatories and planetary probes (both independent and joint) will probably not be matched by the Soviets for some years.

The broad cooperative activity of the United States with its allies in space since 1961 has seeded and stimulated the growth of space science and the associated technologies in many of the nations involved, to the point at which some of their capabilities rival our own. Among ESA member nations, the United Kingdom is highly astronomy-oriented; both West Germany (FRG) and France have strong space science capabilities, and are prime movers within ESA in this field. On roughly one-sixth of NASA's budget, ESA has launched a substantial X-ray satellite (Exosat) on a U.S. Delta launcher and will soon launch a cometary mission (Giotto), a 30-cm telescope (Hipparcos), and a solar-polar orbiter (ISPM), as well as conduct numerous Spacelab science experiments. ISPM is a joint NASA/ESA mission with experiments from both sides, and will be launched on the Shuttle.

Japan is also emerging as a contender in space sciences. Although its primary focus has been on development of commercial applications satellites, the Institute of Space and Astronautical Science (ISAS), responsible for Japanese space activities, sustains a level-of-effort in space science of one launch per year, on average. On less than one-tenth of the NASA space science budget, recent and upcoming achievements of ISAS include an X-ray optical/radio satellite (Hakucho), a solar flare sensor (Hinotori), a larger X-ray satellite (Tenma, or Astro-B), a cometary mission (Planet-A), and an even larger X-ray detector (Astro-C), mounted jointly with the United Kingdom. In developing its capabilities in space science Japan has not relied heavily on cooperative missions with the United States, although much of the supporting technology has been derived from U.S. commercial construction of large portions of its Earth-sensing and communications satellites.

These developments lead to the conclusion that active competition in the space sciences is only now becoming possible. The more nations that possess the capability of developing space technology, the more cooperative options there are. Nations will also decrease their dependence on the traditional center of activity, the United States. In this context, a number of factors come into play in determining the scope and direction of future competition:

- the value of space science as compared with other space activities (e. g., remote sensing and communications);
- the overall space capability of a nation (e.g., launch capability);
- reliability (in terms of schedule, costs, and quality of services and hardware);
- both national and world economic factors (i.e., the relative affordability of space science among nations); and
- institutional factors within nations (e.g., governmental commitment and support, management framework).

Prevailing Issues in Space Science Competition

The potential for more open competition in space science is related to the increase in the world market for space services in general. For example, the possession of space transportation systems and/or orbiting research platforms is a key factor in the competitive position of a nation with regard to all areas of space activity. The ability to develop cost-effective specialized instrumentation and equipment is also an important market factor in every area.

In the absence of commercial interchange, the competition between the United States and the U.S.S.R. has heretofore been primarily the pursuit of prestige. However, **the increase in cooperative activity between the U.S.S.R. and France in recent years suggests that competition between East and West may increasingly occur in the form of competition for cooperative activity with others.** An overall tendency toward the "loosening up" of Soviet space policy would accelerate this trend. This issue is particularly important with regard to Third World countries.

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Developing Countries

The overall issue of how to involve developing countries in space science will become increasingly pressing in coming years. Most of the interest of these countries in space relates to applications-oriented activities, but the need to build a domestic infrastructure for such activities will inevitably dictate some involvement in space science, at least on a modest scale. For the space-capable nations, the problem of how to accomplish this integration at minimal cost and without doing damage to existing programs must be addressed.

Long-Term Agenda for Space Science

Development of a rational, long-term agenda for science missions as related to science objectives is a continuing issue for each of the space-faring nations. It is of particular importance as more nations enter the space arena. Given the pervasive sharing of data, at least in the West, duplication of missions is pointless; yet the decision as to who conducts what missions is an increasingly complex one, and involves issues of competition as well as cooperation. Such agendas are regularly drawn up in the United States, but there is no assurance that they can be adhered to. **The difference between annual budget funding in the United States and, for example, mission funding within ESA, is a critical one from the point of view of U.S. scientists and potential partners alike.**

Along with the issue of program planning goes the separate consideration of maintaining an appropriate balance between space science and applications. This is done now on a largely subjective basis, but the trend toward more expensive science missions and an intensifying competition in the applications area may upset the balance, necessitating a more formal means of assessing the value and interlinkages of each. This is potentially of greatest importance for space science, where the value of findings cannot be easily quantified.

Economic Impact of Space Science

Space science is conducted predominantly by means of sensing and detecting equipment, with data being generated and transmitted by means of advanced electronic systems. The ground tracking and receiving stations are sophisticated facilities, relying on computer systems for most essential functions. Thus, space science is a high technology endeavor, very much a part of the most vigorous sector of our present-day economy. The actual and potential economic impact of space science as both a producer and purchaser of goods and services should be examined. ESA has conducted studies (now somewhat dated) of the economic benefits of space business to ESA contractors.[8] Comparable analyses were conducted for NASA by Chase Econometrics in 1975, but no studies specific to space science contracts have ever been done.

Education and Training

Differences in education and training of scientists and engineers among the space-faring nations constitute another issue. In the United States the system for producing space scientists relies heavily on academic graduate training at a few universities under individual faculty researchers. Additional training occurs on-the-job in industrial project teams. Government contracts provide this system's principal means of support. Yet the unevenness of funding provided to these laboratories and industrial groups in recent years, as a result of funding cuts and a decrease in the overall number of missions, has endangered the system.[9]

In this regard, an 18-percent increase in the overall space science budget for 1984 was a healthy sign, with new missions such as the Extreme Ultraviolet Explorer and the Venus Radar Mapper entering the budgetary picture. The 1985 budget provides for even larger increases in space science funding—about 21 percent—including the Mars Geoscience Climatology Orbiter, the Upper Atmosphere Research Satellite (UARS), and the scatterometer for the Navy's NROSS satellite as new starts in 1985.

[8] *Economic Benefits of ESA Contracts,* ESA BR-02, European Space Agency, October 1979.

[9] *Space Science Research in the United States—A Technical Memorandum* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-TM-STI-19, September 1982), pp. 8, 22.

Especially encouraging in these recent budgets are the substantial increases in funding for continued data analysis of astronomy and planetary missions, as this support is crucial for the maintenance of research groups. The planned space station will hold many opportunities for space science over the long term. In addition, the Shuttle will present numerous opportunities for small-scale instrument development projects, thus broadening opportunities for education and training at U.S. "centers of excel lence. "

INTERNATIONAL COOPERATION IN SPACE SCIENCE

Historical Overview

U.S./Soviet Cooperative Efforts*

Given the persistence of enmity, suspicion, and political competitiveness between the United States and the Soviet Union, the overall level of cooperation in space activities has been remarkable. The primary basis for cooperation has been a "1972 Intergovernmental Agreement on Cooperation in the Exploration and Use of Outer Space for peaceful purposes, " entered upon as the period of U.S./Soviet detente began. This agreement provided for: 1) development of compatible rendezvous and docking systems for testing on a joint U.S./Soviet manned flight, and 2) establishment of Joint Working Groups in four scientific areas:

- Space Meteorology;
- Study of the Natural Environment;
- Near-Earth Space, the Moon, and Planets; and
- Space Biology and Medicine.

The first part of the agreement resulted in the 1975 Apollo-Soyuz Test Project (ASTP), which probably represents the high-water mark of U. S./ Soviet cooperation in space. However, although some joint biological experiments were conducted on board, ASTP was of far greater political than scientific value.

Scientific cooperation with the Soviets has been less dramatic but quite substantive, particularly i n the planetary and life sciences. The planetary working group has held numerous joint meetings and information exchanges relating to solar-planetary physics and lunar and planetary exploration. Lunar samples from several Apollo and Luna sample return missions have been exchanged (including a 2-meter core sample from a 1976 Luna mission). Beginning in 1978, missions to Venus (Soviet Venera and U.S. Pioneer Venus) have been coordinated and data exchanged. This has been particularly beneficial for U.S. scientists in view of the vigor and success of the Soviet Venera program, which has included transmission of color photographs from the planet's surface.

Probably the most comprehensive cooperation, however, has been in space biology and medicine. Three unmanned Soviet Cosmos biosatellites launched in 1975, 1977, and 1978 carried numerous U.S. biological experiments in a broad range of areas, including simulated gravity experiments (via an on board centrifuge). These flights were a valuable opportunity for American space life scientists in a period when no U.S. manned missions (or comparable biological missions) were being flown. Equally important has been the cooperation in ground-based studies, such as the 1978/79 Joint Bed rest Study conducted to standardize procedures for weightlessness simulation in the laboratory. Further significant exchanges took place at the 1980 Joint Symposium on Vestibular Problems and the 1981 Joint Symposium on Cardiovascular Changes Resulting from Spaceflight.

The decision not to renew the May 1977 intergovernmental Agreement in 1982 (see ch. 3) meant that the Joint Working Groups were no longer constituted. Cooperative activity had for the most part dwindled down to a "baseline level" of routine data exchange and interpersonal scientific communication through letters and at international scientific meetings. It is clear that cooperation in space science, as in other areas, between the United States and the U.S.S.R. is tied

*U.S.-Soviet Cooperation in Space–A Technical Memorandum (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-TM-STI-27, in press), to the overall level of diplomatic exchange and political relations between the two countries.[10] Scientists on both sides generally regretted this earlier loss of opportunity. However, recent legislation (Public Law 98-562) signed by President Reagan in October 1984, calls for a renewal of the 1972-77 agreement, and may presage a new level of cooperative science activity between the two nations.

The most durable area of cooperation is in the life sciences, where the United States participated in another Cosmos biosatellite mission in December 1983 (the United States supplied medical monitoring equipment and procedural advice for this primate mission). CAT-scan bone data from Salyut missions are still being supplied to NASA. NASA's Director of Life Sciences attended an international Gravitational Physiology Meeting in the U.S.S.R. in 1983, and exchanges between Working Group members continue on an informal basis. Some results of Venera 13 and 14 were received in early 1982 (including the photographs mentioned earlier), and data from two Venus radar mappers launched in June 1983 (Venera 15/16) were presented at an international conference in the United States.

U.S. Cooperative Efforts With Other Parties

Beginning in the late 194os, the United States actively sought and sponsored Canadian and European participation in its embryonic space research program. Such activities were numerous throughout the 195os, and were heavily subsidized by the United States. * By 1962, cooperative space science projects were being conducted not only on sounding rockets and balloons, but also on orbiting spacecraft.

In the years since, such activities have continued to expand, to the point at which all U.S. space science efforts now involve some foreign participation (if data exchanges, guest investigator programs, etc., are counted). The roster of U.S. partners has grown to include most of the major Western European nations, as well as Japan, Australia, New Zealand, India, Pakistan, Israel, Greece, Peru, Brazil, and Argentina. The offer of a cooperative shuttle flight mission was extended by the President to the People's Republic of China in May 1984. Table 9-1 shows that an increasing number of major U.S. space science missions are truly joint missions, involving foreign-built spacecraft or on board instruments, and foreign principal investigators. It is clear from the table that the United States has been the leading instigator of cooperative missions in space science, even considering the Soviet-bloc cooperative lntercosmos missions, which are not itemized here.

The table also depicts the variety of structures for joint projects–bilateral, multilateral, hosted experiments, etc. Chapter 3 introduced the fact that NASA prefers bilateral to multilateral efforts.[11] Missions such as the International Sun-Earth Explorers (ISEE), which involved the development of separate spacecraft, or the International Radio Astronomy (I RAS), which entailed building separate major components, have proved to be among the smoothest joint undertakings.

The United States has a number of motives for stressing cooperation in space science. Some of these are altruistic-e.g., the desire to extend both knowledge of the space environment and benefits of space science to as many nations as possible, and the wish to foster a cooperative atmosphere among nations. Some are economic—principally, the desire to share costs. And some are political: the desire to broaden diplomatic relations with others, to demonstrate U.S. competency and strength, to strengthen our allies technically and economically, and to foster their greater security and independence. It should be noted that these motivations are equally applicable to any other form of cooperative space activity.

However, the benefits of cooperative space science are not always clear-cut. For example, it is difficult to assess the economic benefits to the United States of foreign participation on U.S. missions, especially where foreign gains out of the project may have exceeded contributions. In

[10] *Soviet Space program: 1976-80* **(Part 1),** Congressional Research **Service, December 1982, pp. 5, 202, 209, 219-20.**

***Frank McDonald, NASA Chief Scientist, refers to this period as "a sort of Marshall Plan in space. "**

[11] *See UNISPACE '82: A Context for Cooperation and Competition,* **op. cit., app. B.**

Table 9-1.—International Cooperative Ventures in Space Sciences

Launch year	Mission name	Cooperating countries	Space science objectives
1962	Ariel-1	U. SJU.K.	Measure energy spectrum of cosmic rays, solar X-rays
1962	Ariel-11	U. S./U.K.	Measure galactic radio noise, micrometeoroid flux
1967	Orbiting Solar Observatory-4 (0s0-4)	U.s.[a]	Measure solar X-ray distribution, H_e emission
1968	Orbiting Geophysical Observatory-5 (OGO-5)	U.K.[a], FF	Determine direction of incidence of primary cosmic rays and density itemperature of H in geocorona
1969	0s0-5	U.K.[a], FF	Measure solar X-ray flux and self-reversal of Lyman-Alpha line
1969	0S0-6	U.K.[a], It[a]	Study solar H_e resonance, X-ray and gamma radiation
1969	Apollo-1 1	Switz[a]	Measure composition of solar wind
1969	Apollo-12	Switz[a]	Measure composition of solar wind
1971	Ariel-IV	U. K./U.S.	Measure VLF radiation and cosmic radio noise
1971	Barium Ion Cloud Probe	FRG/U.S.	Barium release to stimulate action of solar wind on comet tail
1971	APollo-14	Switz[a]	Measure composition of solar wind
1971	Apollo-15	Switz[a]	Measure composition of solar wind
1972	Apollo-16	Switz[a]	Measure composition of solar wind
1972	Orbiting Astronomical Observatory-3 (OAO-3)	UK.a	Study stellar ultraviolet and X-ray emissions (project also known as Copernicus)
1972	A EROS	FRGAJ.S.	Measure solar extreme UV and correlate with upper-atmosphere components
1972	Apollo-16	FRG[a], FP	BIOSTACK I (effects of CR on selected biosystems)
1972	Apollo-17	FRG[a], FF	BIOSTACK II (effects of CR on selected biosystems)
1973	Skylab	FP, Switz[a]	Sky survey, distribution of galaxies and ionized hydrogen; and solar wind analysis
1974	Astronomical Netherlands Satellite (ANS)	Neth/U.S.	UV photometry and X-ray emissions
1974	Ariel-V	U. K./U.S.	Conduct X-ray sky and survey and locate sources
1974	Helios-1	FRG/U.S./It/Aus	Measure micrometeoroid flux, study solar X-rays and mass, and planetary orbits
1975	Apollo-Soyuz Test Project	U.S./U.S.S.R.	Rendezvous and docking test included joint biological studies
1975	Apollo-18	FRG[a]	BIOSTACK-111 experiment aboard U.S. craft in ASTP
1975	Aryabhata	India/U.S.S.R.	Solar and upper atmospheric research
1975	Cosmos 782	U. S. S.R.[b]	Eleven U.S. experiments aboard (including centrifugation)
1975	0S0-8	F F	Spectrographic study of solar chromosphere
1976	Helios-2	FRG/U.S./It/Aus	Measure micrometeroid flux, study solar X-rays and mass, and planetary orbits
1977	International Sun-Earth Explorer-1 (ISEE-l)	U. SJESA	Coordinated spacecraft studied magnetosphere, interplanetary space, and their interaction
1977	ISEE-2	ESAW.S.	Coordinated spacecraft studied magnetosphere, interplanetary space, and their interaction
1977	SIGN E-3	U. S. S. R.lFr	Observatory with telescopes for locating CR sources
1977	Cosmos 936	U. S. S.R.[b]	Seven U.S. biological experiments
1977	Cosmos 936	U. S. S. R.lFr	French biological experiments aboard
1978	ISEE-3	FRG[a], FF, Neth[a]	Solar wind composition and mapping; comet flyby
1978	Pioneer Venus-2	FRG[a], FP	Atmospheric and cloud studies at Venus
1978	NASA Heliocentric Mission (ISGE-3)	U.K,a	Solar proton behavior in interplanetary space
1978	Cosmos 1129	U. S. S.R.[b]	Fourteen U.S. biological experiments
1978	Cosmos 1129	U. S. S. R.lFr	French biological experiments aboard
1978	International Ultraviolet Explorer (IUE)	U. S. IESAW.K.	UV spectroscopy
1979	High Energy Astronomical Observatory-3 (H EAO-3)	F@, Dk[a]	Study galactic CR composition
1979	Hakucho	Japan[b]	Optical and radio observations of X-ray stars
1980	Solar Maximum Mission (SMM)	U. S./NethW. K.[a]	Solar hard X-ray imaging spectrometry
1982	SOyUZ T-7	U. S. S. R.lFr	Biomedical tests, “Aelita” diagnostic device
1983	Infrared Astronomical Satellite (IRAS)	Neth/U.S.W. K.	Conduct IR sky survey

Table 9-1 .—International Cooperative Ventures in Space Sciences—Continued

Launch year	Mission name	Cooperating countries	Space science objectives
1983	Optical-X-ray Observatory	U. S. S. R./Fr	UV and X-ray spectrometry
1983	Spacelab-1	ESAW.S.	Multinational experiments include biology, medicine, botany, astronomy, and solar physics
1983	San Marco-D	Itlu.s.	Effects of solar activity on meteorological processes
1983	Cosmos-1514	U. S. S.R.[b]	U.S. providing medical research devices for primate mission; U.S. biological experiments
1984	Active Magnetospheric Particle Tracer Explorer (AMPTE)	U. S.IFRG	Study solar wind, identify particle entry windows, energization and transport processes into magnetosphere
1984	Long-Duration-Exposure Facility (LDEF)	FRG[a]; U. S.llre/ESA[a]; Switz[a]; U.K.	Investigations of space environment
1985	Spacelab-2	U.K.a	Galactic X-ray imaging and determination of H_e abundance in solar corona
1985186	International Halley Watch	ESA/U.S.S.R.; JapanW.S.	Spacecraft and mission design are being coordinated for ESA'S Giotto, U. S. S.R.'S Venera-Halley (2), and Japan's Planet-A. U.S. coordinating ground-based and near-Earth obsewations
1985	Giotto	ESA[b]	Multi-parameter characterization of cometary environment
1985	Spacelab-3	India[a]	Study solar/galactic CR ionization states
1985	Sp'acelab-D-l	U. S./Can[b]	"Space Sled" to conduct neurophysiology research
1985	Gamma-1	U. S. S. R.lFr	Gamma ray source detection
1986	Galileo	U. S./FRG	Broad investigation of Jupiter environment
1986	Hubble Space Telescope	U. S./ESA	High-resolution coverage of optical and UV wavelengths
1986	Ulysses— International Solar Polar Mission (ISPM)	ESALI.S.	Observations of Sun and interplanetary medium out of the ecliptic plane
1987	Roentgen-Satellite (ROSAT)	FRG/U.S./U.K.	X-ray sky survey and sources study
1987	Ast ro-C	Japan/U.K.	Study spectral and time variation in X-ray sources
1987	Cooled submillimeter	U. S. S. R.lFr	Study spectra of 0.1 to 2.0 mm radiation
1987	Sigma	U. S. S. R.lFr	X-raylgamma telescopy and burst detection
1988	Gamma Ray Observatory (GRO)	U. S.IFRG[a]	Wide-range gamma ray detection
1988	Venus Radar Mariner (VRM)	U. S. lF@	Venus gravity and atmospheric tides

NOTES:
1. Table includes, in the case of future missions, only those officially approved. Tables does not include cooperative sounding rocket, balloon, and ground-based projects; also excluded are incidents of data exchange or launch services only.
2. Multilateral joint ventures among ESA member countries are considered as ESA missions. However, national project activities involving ESA members with non-ESA countries are considered as national cooperative ventures.
3. Multilateral joint ventures among Soviet bloc countries under the Interkosmos program are considered simply as Soviet missions.
4. Fr = France; U.K. = United Kingdom; It = Italy; Switz = Switzerland; FRG = Federal Republic of Germany; Neth = Netherlands; Aus = Austria; Dk = Denmark; Ire = Ireland.

[a]Foreign experiment (foreign Pl) on U.S. mission.
[b]U.S. experiment on foreign Spacecraft.

the present era the latter has not been a large consideration. NASA solicits foreign proposals along with domestic ones, and selection of experiments is made "blind. " NASA officials insist that only the best science is flown. However, some U.S. scientists often object that any inclusion of foreign experiments is detrimental to U.S. scientific interests: U.S. teams lose valuable opportunities for support, and opportunities for U.S. development of technology are also lost. There is also the frequent complaint that NASA's periodic difficulty in funding science on American missions (particularly in the case of Spacelab) means that, in effect, the American taxpayer has paid for providing inexpensive science opportunities in space to researchers of other nations.

However, as the technical capabilities of our partners have increased, the scientific payoff from cooperation has become increasingly evident. The network of three satellites in ISEE (see table), for example, was significantly enhanced by the inclusion of the ESA satellite as well as by the foreign experiments present on all three spacecraft.

The one fact that has lent potency to many of these criticisms in the past, however, has been the lack of reciprocity for U.S. scientists as principal investigators on ESA missions.[12] ESA has now agreed to permit U.S. proposals in response to its Announcements of Opportunity. There is now a quota which is determined on a case-by-case basis, and procedures for carrying out the new policy are being implemented. Officials of both ESA and NASA feel that the bottleneck will now be NASA's ability to fund U.S. experiments on ESA missions.

Soviet Cooperative Efforts With Other Parties

The U.S.S.R. entered the cooperative arena in space science more than 10 years after the United States. Its primary vehicle for international cooperation is the Intercosmos program, which was constituted in 1967 (with the first launch in 1969) to coordinate joint activities with Eastern European and other communist countries. The scientific program includes space physics and life sciences, in addition to more applications-oriented space research. Over the first several years a few scientific satellites were flown under the Intercosmos label, but the focus of the program appeared to be more political than genuinely scientific or even genuinely cooperative.

But the Intercosmos program took on added dimension in 1976 when it was integrated into the manned spaceflight program. Under this plan, cosmonauts from the member countries fly, one by one, on Soviet missions to the orbiting Salyut space station. Thus far, these have been "visiting crews, " dedicated to specific science objectives and typically lasting 8 days. The foreign cosmonaut is a "flight engineer" or "research engineer" (not the commander). Instruments or experiments developed by the Intercosmos member country u rider Soviet direction are flown up for use during the mission. The program appears to have been highly successful and advantageous for the Soviets, in the sense that they have gained much political capital vis-a-vis the' participating countries.

Apart from the Soviet bloc countries, Soviet cooperative activities in space have extended only to the United States, France, India, and Sweden. The relationship with France has been especially fruitful, and has involved quite substantive missions: an observatory for locating cosmic ray sources (SIGNE 3, 1977); life sciences experiments onboard Cosmos 936 and 1129 (1 977/78); instruments on the Lunokhod landers, Mars, and Venera spacecraft; and a UV spectrographic instrument on the Prognoz station. Aread 3 (August 1981) has returned data on magnetosphere-ionosphere coupling; the UFT spacecraft, an optical and X-ray astronomy observatory was launched in March 1983. Plans for a joint Soviet/French mission to Venus in which French-made balloons would be released into the atmosphere were recently altered to enable the Soviet spacecraft to continue on to Halley's comet (see discussion of the International Halley Watch below).

But the most striking cooperative project was the inclusion in 1982 of a French cosmonaut in the second crew to visit Salyut-7. A substantial element of the mission was the installation of a French medical diagnostic device, Aelita-1, aboard the station.[13] Gamma 1, a high-energy gamma ray observatory (1986), Sigma, a more sophisticated gamma ray facility (1987), and a cooled submillimeter telescope (1987).[14] Plans for a Venus/asteroid lander in 1991 will probably involve France as well.[15]

France has engaged in this cooperation with the Soviets in a spirit of objective pragmatism. The French space science community has been able to make great strides through access to Soviet launchers and the well-developed Soviet space program. Meanwhile, French technical skills have significantly enhanced the Soviet capability, particularly in astronomy and the application of electronics. The U.S.S.R. has also been able to gain considerable diplomatic advantage through the relationship with a major Western nation, and has

[12] *Space Science Research in the United States,* op. cit.

[13] According to recent agreements, the same device will be flown aboard the U.S. Shuttle when a French astronaut participates in a U.S. mission in 1985.

[14] Nigel Hen best, "Astronomy-The Next Space Race, " *New Scientist,* Mar. 31, 1983.

[15] *Aviation Week and Space Technology,* Apr. 1, 1985, pp. 18-20.

capitalized on opportunities afforded by U.S. space science program cuts.[16] The collaboration appears to have been mutually satisfying overall, although private discussions reveal some dissatisfaction on the French side with Soviet bureaucratic processes.

The other major Soviet cooperative activity with a non-Communist nation has been with India. With the exception of the first Indian satellite, Aryabhata (1975), dedicated to solar and atmospheric studies, and an Indo-Soviet balloon experiment in gamma ray astronomy in 1979, the joint projects have been applications-oriented. However, an Indian cosmonaut visited the Salyut-7 station in April 1984.

Beginning in the early 1970s, India has parlayed a very modest investment in space into a creditable program which is now nearing self-sufficiency. To do so it has relied on assistance primarily from the United States, the U. S. S. R., and France, and on a substantial pool of domestic scientific talent. In the process it has successfully maintained a balance between independence and cooperation, becoming a model for Third World countries not only in the development of a space program, but also in dealing with the superpowers. It is partly India's leadership role in the Third World that attracts Soviet attention, for India represents a lever by which the space-related organizations at the U.N. can be influenced.

European Space Agency: Cooperative Outlook

Through ESA, the advanced European nations have been able to mount a space program comparable in scale with those of the United States and the U. S. S.R.[17] Although a primary area of endeavor is space science, ESA's budget (currently about 16 percent of NASA's) permits it to launch a medium-class space science mission only every 18 months. Cooperative activity, with the United States and with individual member nations, increases considerably the rate of participation in space science.

Because of its limited budget, ESA has had to conduct a more focused science program than the United States or the U.S.S.R.—mostly astrophysics and astronomy, and some life sciences. (Since space life sciences work falls within the "optional" category of programs, it tends to be dominated by individual nations, principally France.) The Giotto mission to Halley in 1985 will be the agency's first planetary mission. Also, no autonomous manned space activities have been attempted (the German payload specialist aboard Spacelab 1, Shuttle flight 9, was the first ESA astronaut). Nevertheless, ESA's accomplishments in space science have been considerable. Cooperative missions such as International Ultraviolet Explorer (IUE, 1978) and International Sun-Earth Explorer (ISEE, 1977/78) have produced some of the best science, and have been virtually textbook cases of international joint ventures.

The subject of reciprocity for American principal investigators on ESA missions has already been discussed. One point relative to that issue, and to ESA's long-term resistance on it, is that (unlike NASA) ESA does not save money when American experiments are flown; rather, the member countries do, on a proportional basis. Therefore, the loss of opportunity to a prospective European principal investigator looms much larger as a factor. ESA has ultimately agreed with NASA's position that its program has reached maturity, and that U.S. assistance over the years must now begin to be, in a sense, paid back.

Current or Planned Programs

As was pointed out earlier in this chapter, because of the increasing capabilities of space-faring nations as a whole, cooperative ventures are increasingly common and increasingly affect the competitive balance of the nations involved in space and space science. The following brief case studies illustrate the ways in which this dynamic is being altered.

Infrared Astronomical Satellite (IRAS)

This trilateral mission was launched in January 1983, and was the first major astronomical satellite launched since 1978. A short-lived survey telescope, IRAS was first conceived by the Dutch

[16] *Soviet Space* **Programs:** *1976-80,* **op. Cit., pp. 288-289.**

[17] For a full **discussion of** ESA's **evolution and its programs,** see *Civilian Space Policy and Applications* **(Washington, DC: U.S. Congress, Office of Technology Assessment,** OTA-STI-177**, June 1982), pp.** 176-187.

but, at nearly $300 million, was not affordable as a national project. The Netherlands approached the United States for assistance, and the cost was split three ways among the Netherlands, the United States, and the United Kingdom. The spacecraft was built by the Netherlands, with the United States providing a cryogenically cooled infrared telescope and detectors, and the United Kingdom providing the ground control and operations facility. The United States launched IRAS. Although the detectors aboard the satellite functioned as planned for only 11 months,[18] it returned a wealth of new scientific data on infrared objects that were previously unobservable.

[18] The liquid helium used to cool the infrared detectors boils away over time, limiting the life of the detector to the lifetime of the available helium coolant.

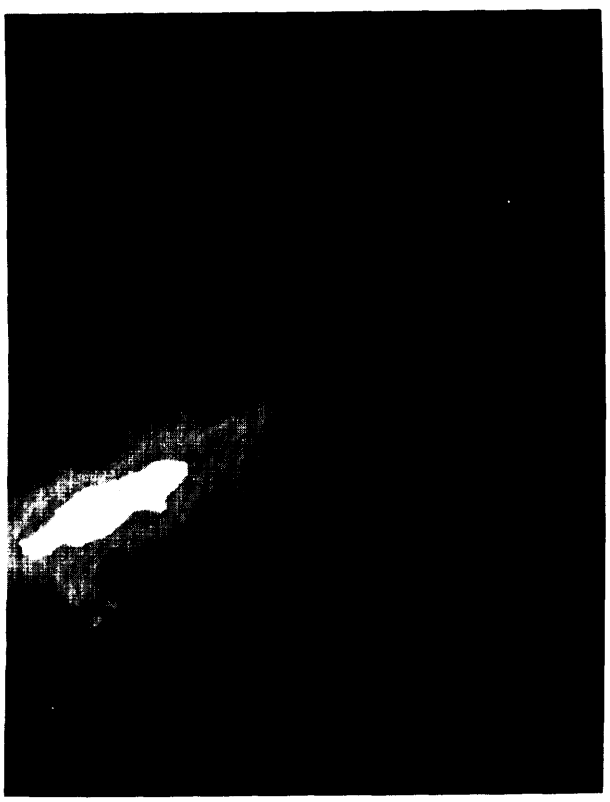

Photo credit: National Aeronautics and Space Administration

Infrared image of the center of the Milky Way galaxy taken from the Infrared Astronomical Satellite (IRAS). The Netherlands and the United Kingdom participated with the United States in this survey mission.

Significant IRAS findings include:

- a suspected burned-out comet,
- dust in the asteroid belt,
- a ring of interstellar dust and solid particles orbiting the star Vega, and
- infrared-emitting galaxies.

International Halley Watch (IHW)

This designator refers to the network of ground-based observations and data coordination that NASA will provide during the Halley missions in 1985-86. NASA will fund several international observational networks in addition to its own Deep Space Network; these will form the link between Earth-based and in situ observations of the comet ephemeris (positional data). NASA will also make supporting observations from Earth orbit via a collection of ultraviolet telescopes aboard the Shuttle, known as Astro-1.

Until mid-1982, there was a possibility that NASA would fund a Halley Earth Return Mission. That mission was not approved, so four spacecraft will travel to the vicinity of Halley: ESA'S Giotto, two Soviet Venus-Halley (Vega 1 &2) spacecraft, and Japan's Planet-A. This will be a first planetary mission for both ESA and Japan. NASA's decision not to mount a mission was based partly on the fact that large quantities of in situ data will be collected by the already planned missions. In addition, NASA is supporting U.S. co-investigators on nearly every Giotto experiment. Interestingly enough, a U.S. instrument is being flown aboard one of the Soviet Vega spacecraft.[19]

There has been considerable multinational communication among these participants (including NASA), and an "Inter-Agency Consultative Group" has been established to coordinate encounter strategy and other matters relating to the space missions. A "Spacecraft Navigation and Mission Optimization Group" within this organization will provide the link between IHW ground observations and imaging data obtained aboard the various spacecraft. Data acquired from the U.S.S.R. Vega 1 probe will provide posi-

[19] John Noble Wilford, "U.S. Device Riding Soviet Spacecraft, " New York Times, 12/21/84, p. A.1.

tional data needed by ESA's Giotto spacecraft in its attempt to come within 1,000 kilometers of the comet's nucleus. The Vega spacecraft will precede Giotto by several days, allowing its observations of the comet to be used in a final course correction of Giotto.

Space Telescope (ST)

This is one of only two large U.S. astronomical satellites currently approved (the other is the Gamma Ray Observatory). Due for launch in 1986, it will be the most important telescope of the decade, putting in space a 2.4-meter telescope with an innovative "honeycomb" mirror. Instruments at the focal plane will include two cameras, a spectrograph, and a photometer to cover the UV and optical spectrum. ESA is contributing a Faint Object Camera, in the development of which seven countries are participating. ESA will also provide the solar array and ground operations support. In return, ESA astronomers will receive 15 percent of the observing time.

This telescope will be able to detect objects perhaps 100 times fainter than are observable with ground instruments, and is designed to last at least 15 years. NASA Administrator Beggs terms it "literally . . . a cooperative effort of the world's astronomical community."[20] An important element of this cooperation is the creation by the United States of the Space Telescope Science institute, in which scientists from many countries are working to ensure thorough dissemination and analysis of ST data.

Astro-C

This will be the third in a series of increasingly large and sensitive Japanese X-ray satellites. Unlike its predecessors, however, Astro-C is a joint mission between Japan and the United Kingdom. Japan prefers the autonomy of a national mission—its space science budget, roughly as large as ESA's, will usually permit it. The United Kingdom also prefers national projects, but has not had one since about 1977. It has, however, had considerable X-ray experience in the Ariel series, so Japan asked it to develop the very large detector, to be accompanied by smaller Japanese detectors similar to those already flown. The United Kingdom is now a "junior partner" in almost every current joint astronomical mission.

International Solar Polar Mission (ISPM)

Planned initially as a completely joint ESA/U.S. mission, ISPM became something of an international cause celebre when the United States canceled the most important part of its side of the mission. The mission was to consist of two spacecraft (one from each agency) which would fly well out of the plane of the solar system to cross the north and south poles of the Sun. When NASA was faced, in the Reagan Administration's first budget, with a large reduction, it became necessary to cut either the Galileo mission, ST, or ISPM. ISPM was tapped–that is, the U.S. spacecraft was canceled. However, the United States will still launch the ESA satellite, provide tracking and data relay, and fund a number of experiments on the remaining satellite.

The European reaction was unexpectedly strong and outraged. ESA had spent $100 million on the project, and was counting on the unique stereoscopic view of solar phenomena made possible by two satellites. In addition, European scientists planning to fly experiments on the U.S. craft lost their opportunities. The affair has since cooled down, although it is even now a sore point raised as an example of the dangers of international cooperation on a major project.

Outlook for Future International Cooperation

In some respects, the era of small-scale missions performing valuable space science is nearly over. All new planetary missions and all manned and most biological missions are expensive; the next generation of cooled IR and X-ray observatories will also be expensive. State-of-the-art missions in space science will increasingly require multi-funding cooperation in order to be done. ROSAT, Galileo, GRO, Starlab, FUSE, OPEN, ISTP (see table 9-1)—the list of planned and proposed joint ventures is long—and U.S. commitment to cooperate remains strong. The President's "National Space Policy," announced in July 1982, reaf-

[20] An Interview with James M. Beggs, *Sky & Telescope,* October 1982, p. 332.

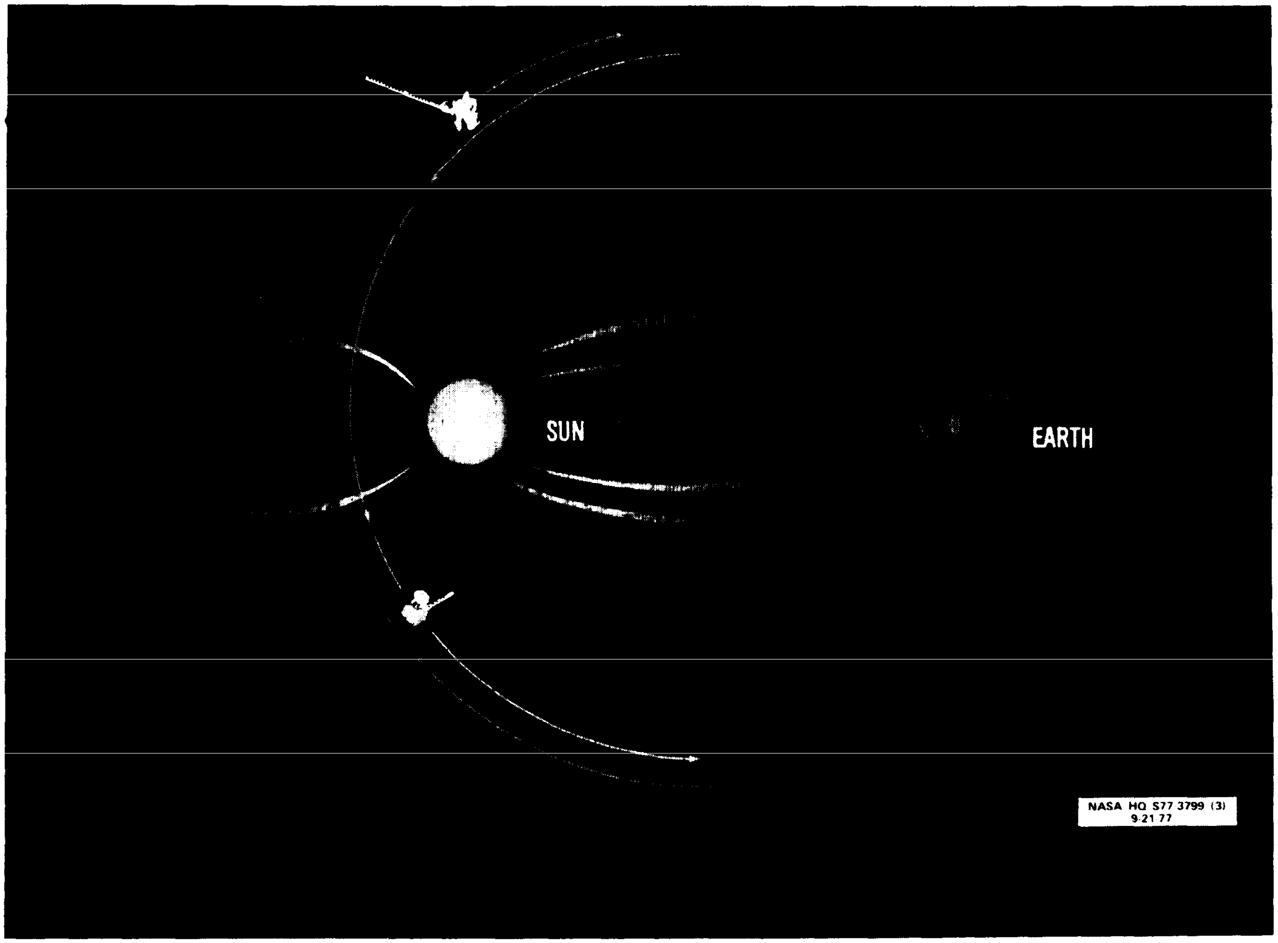

Photo credit" National Aeronautics and Space Administration

Artist's conception of the International Solar Polar Mission in its original configuration. NASA and ESA were to have flown two separate satellites, each in opposite directions over the Sun's poles. There will now be a single ESA satellite with participation from the United States. In this drawing the solar wind (cosmic rays emitted by the Sun) is depicted by the snake-like trail emanating from the Sun. The arrows indicate material that the Sun emits from its polar regions.

firmed the need to "promote international cooperative activities in the national interest" as a basic goal. This goal was reemphasized in the State of the Union Address delivered in January 1984, in which the President expressed his expectation that "NASA will invite other countries to participate" in a U.S. space station effort.

The concerns provoked by ISPM and by U.S. budgetary uncertainties in general have brought about a change in outlook more than behavior: "We learned a great deal about the U.S. budgetary processes, " as ESA'S Washington representative puts it. ". . . We shall be more cautious in the future about drawing up agreements. " NASA's Director of International Affairs, Kenneth Pedersen, asserts that there are three assurances that NASA can offer ESA: 1) the ISPM experience, with its repercussions, makes it less likely that similar events will take place in the future; 2) budgetary austerity means that only top-priority (and therefore not expendable) science projects will be approved; and 3) space science is on the upswing within NASA.

Jointly coordinated planning and management will probably be essential in the future. One approach is the current activity of a Joint Working Group of the NAS Space Science Board and the Space Science Committee of the European Science

Foundation toward establishing a framework for the joint conduct of future planetary exploration. These discussions include formulation of a strategy in terms of science goals and missions, and definition of a desirable approach to long-term cooperation.

The broadening of cooperation will inevitably require the leading countries in space to deal on a policy level with the pressure from Third World countries for participation, as expressed recently by some members of the Committee on the Peaceful Uses of Outer Space (COPUOS), delegates to UN I SPACE '82, and attendees at the February 1983 Intergovernmental Meeting of Space Technology Experts.[21] This consideration is not as directly relevant to space science, however, as it is in the areas of launcher development and applications-oriented space activity. Nevertheless, it will play a role in the space sciences, particularly in light of the Soviets' apparent willingness to train and fly cosmonauts from developing countries (e.g., India). **The United States must remain cooperative in order to remain competitive.**

[21] *UNISPACE '82: A Context for International Cooperation and Competition,* **op. cit.**

THE ROLE OF COMPETITION IN SPACE SCIENCE

It is a truism, certainly in our free market system, that competition promotes better performance. This applies in space science as well, whether on a national level, between research teams and laboratories, or on an international level, between space agencies. But competition in space science works to the advantage of some more than others. There are many factors at work other than sheer technical and scientific capability. Institutional and economic variables on the national level come equally into play. For example, the amount of funding allocated is obviously a major factor. But also important is the degree of governmental commitment to an endeavor that will not immediately produce revenues or increase the standard of living of the populace.

This "willingness to take a risk" is essential; if, for example, a country provides governmental support for the training of graduate students in astrophysics, then that activity is more likely to flourish competitively. The style of management accorded space science R&D and missions operations is another important factor; a cumbersome, multilayered bureaucracy will not allow efficient conduct of space science. Long-range planning is also crucial: it must include realistic goals, an intelligent assessment of scientific priorities, and a shrewd appraisal of foreign plans. The degree to which scientific opinion enters into the planning process is also a factor.

All of these factors combine to shape a country's competitive posture. It may then be asked, does a country's competitive strength, gauged by these criteria, determine its standing among nations participating in space science? Are there clear winners and losers on the international scene?

Prospects for a "Space Science Race"

The answer to that question, for the moment, appears to be "no." In large part this is because two of the principal players, the United States and the U. S. S. R., have for decades had the game essentially to themselves. They have competed, but only at times "head-to-head," and in any event there was no actual prize to win, beyond political prestige. Each nation has essentially cultivated its own group of proteges. In the case of the West, some of these client nations have only recently begun to acquire a degree of self-sufficiency in the support of space science programs. There is not yet adequate scope or momentum in these programs to surpass the United States in any area.

Space science missions are selected out of a common pool of ideas that, in most cases, have been around for more than a decade. There is no element of surprise. There is certainly no point in duplication of missions, or in racing to launch.

A case in point is ESA's decision to build an Infrared Space Observatory (ISO), which will be similar in performance to NASA's planned Shuttle Infrared Telescope Facility (SIRTF). The likely outcome is two separate missions with overlapping but independent experiments to prevent too much duplication. In general, scientific data are shared fully in the West, and it is to the benefit of all concerned to continue doing so. The continuing flow of information even between East and West makes this point clear.

To say that there appears to be no scientific space race in prospect is not to say that competitive factors have no impact. institutional commitment and funding levels will inevitably affect the rate, efficiency, quality, and economy of missions mounted and science performed. The positive image and reputation for reliability thus gained would then make a country an attractive cooperative partner, not only in space science but in the more commercial areas of space activity as wel l.

One further point that should be made is that it is only i n the planetary sciences that there are tangible "prizes" to be won. Soviet spokesmen have consistently hinted at an agenda consisting of: 1) permanent manned presence in Earth orbit, 2) colonization of the Moon, and 3) manned missions to Mars.[22] The first step is already a reality, for all practical purposes. Any resumption of an active "space science race" between the United States and U.S.S.R. would likely focus on the second. However, science would only be incidental to such a contest.

Current Ranking of Participants

It was pointed out earlier that technical, economic, and institutional factors determine a nation's "competitive posture" for space science, and that this affects its ranking among nations—although historical factors are at this point predominant. The following is a brief assessment of the ranking of the four major entities in space science:

- **United States. The United States is clearly the overall leader in space science. This is true** even in view of the fact that only one mission (Solar Max) was launched between 1978 and 1983, while resources were being focused on the space shuttle. U.S. current weaknesses in X-ray astronomy will be rectified (it is hoped) by the proposed Advanced X-Ray Astronomical Facility (AXAF); but at any rate will be improved by participation in the German ROSAT mission. The languishing planetary program will be revived by the Galileo mission to Jupiter and by the Venus Radar Mapper (a new start in 1984) and a proposed Mars Geoscience/Climatology mission (a new start in 1985). Life sciences is being resumed in earnest on Spacelab, with two dedicated Spacelab life sciences missions tentatively scheduled for 1985 and 1986.
- **European Space Agency.** ESA's development in space science during the 1970s was rapid, as demonstrated by the ESRO and HEOS satellites, and especially by COS-B, a highly successful gamma ray satellite. A number of important joint missions with the United States augmented its autonomous programs in astronomy and astrophysics, which are now being continued with Exosat and Hipparcos. ESA's venture to Halley's comet is its first planetary mission. On the basis of technological sophistication and diversity of science, ESA is ahead of the U. S. S. R., although not by a wide margin.
- **Soviet Union.** The Soviet Union ranks ahead of Japan principally on the basis of its highly successful Venera series. Using vacuum-tube technology to withstand the planet's high surface temperature, this program has been impressive. Another strong mission is Venera-Halley, which will drop probes to Venus and continue on to rendezvous with the comet. The U.S.S.R. is also advanced in the life sciences, both animal and plant–chiefly because of the huge number of man-hours in space that its Salyut program has afforded. The Soviet effort in astronomy relies to a great extent on French technical capability.
- **Japan. This country is fourth, but is probably moving the fastest. It currently has a narrowly**

[22] *Salyut: Soviet Steps Toward Permanent Human Presence in Space,* op. **cit., p. 4.**

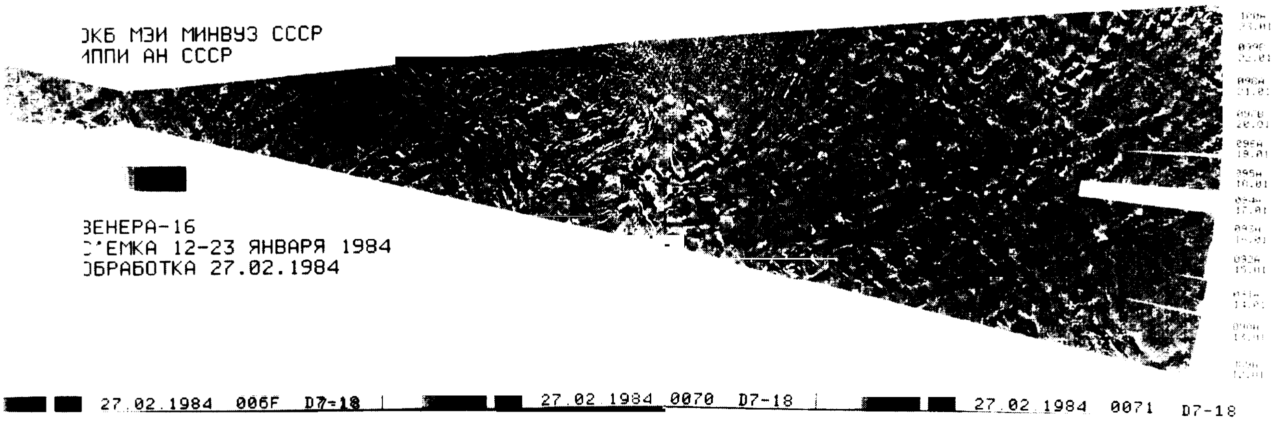

Photo credit: Institute of Space Research, U.S.S.R. Academy of Sciences

Radar image of surface of Venus from Soviet Venera 16 spacecraft, January 1984.

focused program of solar-terrestrial and astrophysics research. The Planet-A mission to Halley will be its first planetary mission. Japan has about one-tenth of NASA's budget for space expenditures, and like NASA's, the overall budget has not grown substantially in recent years. I n Japan, space science research is conducted by the Institute of Space and Astronautical Science (I SAS), a division of the Ministry of Education. Although the budget for space science has increased substantially in recent years, most of the increase has gone for the construction of a new campus on the outskirts of Tokyo. Thus, of the $80 million fiscal year 1983 budget for ISAS, $58.5 million went for space science and observations and $0.5 million for the high-altitude balloon program, with the remaining $21 million for various overhead costs; the increase for space science and observations in the fiscal year 1984 budget was a modest 4.3 percent, bringing its total to some $60.9 million. With the advent of a U.S. space station, Japanese spending for space science could be expected to rise more sharply. A Japanese space official estimates that Japan is 5 years behind ESA and 15 years behind the United States in space science. The new ISAS facilities, however, should position Japan well for future efforts to overtake ESA.

Tradeoffs Between Competition and Cooperation

The conduct of space science in a cooperative yet increasingly competitive atmosphere gives rise to some crucial policy issues. For example, the reduction of opportunities for U.S. space scientists In recent years brings to a sharper focus the criticisms of our open policy toward foreign proposals. There is a tendency toward a protectionist attitude among scientists, who view some collaborative efforts as "giveaway s." The only answer to this is to ensure that foreign experiments win approval on their own merits in every case, and that foreign governments pay their full share of every joint project. Yet policy decisions may occasionally override these considerations, particularly in the case of Third World countries. A policy for dealing with this issue will be required.

There is, as yet, no formal policy for dealing with the issue of technology transfer. Currently such decisions are made on a case-by-case basis, and there is room for error here. Such a policy will be difficult to implement, because the concerns are specific to each case. Often, there is no problem because the technology is packaged in such a way that it cannot be compromised. But the growth of cooperative activity (e.g., between the French and the Soviets) increases the risk of loss from both primary and second-party transfer. Our cooperative partners in space science are increasingly likely to be our industrial competitors.

Markets for Hardware and Services: Space Science as Growth Industry

In recent years the most vigorous and dynamic areas of the U.S. economy have been the high-tech fields: electronics, data processing, communications, robotics. The conduct of state-of-the-art space science relies to a great extent on these fields, and on specialized applications such as high-quality optics and sensors. The value of this endeavor to the stimulation of further growth in these fields, and thus in the economy, has not yet been estimated. However, in the context of an overall NASA space science budget of $1,030 million (fiscal year 1985), it is clearly considerable.

What are the essential products and services at issue? They fall into three categories:

- **Instrumentation.** This category includes all sensing devices and associated hardware mounted on a scientific spacecraft: telescopes (including mirrors, lenses, housings, and mechanisms for placing instruments at the focal plane); detectors (e.g., gamma ray, X-ray, IR) and spectrographs, cameras, and associated systems such as cryogenic cooling apparatus. Major variables affecting cost and availability include spectral resolution and sensitivity.
- **Spacecraft.** This is essentially the development of numerous variations on a theme, with main components being the mounting platform, an electrical bus for powering the instruments, and a system for thermal control. The technology is fairly standardized. One area where R&D is still quite active is in the search for ways to improve pointing accuracy and stability (accomplished by feedback loops between the instruments and the attitude control system). The improvement of on board computer technology in terms of storage capacity and data rates is another developing area. Most systems (e.g., gyroscopes) are not particularly competitive in terms of technology. U.S. manufacturers dominate the field internationally, and are closely grouped in the sense of product capabilities, performance, and quality. The real competition here is in price and reliability.
- **Data Processing. This category includes all** computer systems and facilities on the ground for reception, analysis, and dissemination of spacecraft data. This area is the least relevant to a discussion of the national and international markets, since most U.S. missions do not require new facilities but rely on existing equipment at JPL (planetary missions) and Goddard Space Flight Center. Because this is the least critical area relative to mounting space science missions, large differences in ground-link data processing capability among nations have relatively little effect on space capability. (A case in point is the U. S. S. R., which has only in the past 2 years modernized its ground control facilities approximately to a mid-1970's level of U.S. computer technology.) Nations with *no* capability (e. g., The Netherlands) generally exchange scientific data for tracking and data processing services.

International Trade Factors

There are 13 U.S. space systems manufacturers, with two or three times that number supplying major components. Of these, only five have ever manufactured space science spacecraft: Hughes, Boeing, TRW, Grumman, and Ball Bros. * This fact indicates as well as any other statistic the small size of the market in this area relative to that for launchers, applications satellites, and military systems. In dollar terms, the domestic market amounts to about 85 percent of the NASA space science budget in any given year (e. g., roughly $716 million in fiscal year 1984), for systems, components, and data analysis.

The main point to be made is that, although there is a national market, there is only a very small international market in space science technology. Boeing has contracted to Sweden to build the Viking satellite, at a cost of $9 million to $10 million. Ball Bros. manufactured parts of the IRAS spacecraft. The total annual U.S. sales to foreign

* RCA and GE, however, have built research satellites for Earth science missions.

countries, including components and spares, does not exceed $50 million, and in some years is less than $20 million. Foreign space programs are generally required—whether implicitly or explicitly–to keep their business at home. It is significant that no U.S. company has foreign sales representatives for these systems.

Foreign companies' sales to the United States are even more limited. The solar arrays on Space Telescope will be built by British Aerospace. The German firm Telefunken manufactures traveling wave tubes that have been bought by U.S. manufacturers for use in on board communications systems. Zeiss is a competitor of Perkin-Elmer in optics. But in general, U.S. companies are far ahead of their foreign counterparts in the development of space science satellites and systems.

One development having potential implications for the stimulation of a market in this area is Boeing's development of MESA, a "generic" platform satellite similar to that being supplied to Sweden. Their approach is to offer a low-cost, standardized bus and then to assist scientists in shaping the experiment to fit within its parameters. Boeing is marketing this system internationally with the help of Arianespace and Matra, the French space companies.

SPACE SCIENCE IN DEVELOPING COUNTRIES

The Allure of Space Science

Any discussion of this topic must be prefaced by an acknowledgment that the interest so vocally expressed by Third World countries in greater participation in space activities is explicitly an interest in the "practical" side of space: television and telephone communications for business, educational, medical and other purposes; remote sensing of their terrain and weather; launcher services, etc. Chapters 3, 6, and 7 in particular address these major aspects of the subject. Astronomy or planetary exploration for their own sake are "luxuries" that the Third World cannot yet contemplate.

Yet there is a small but essential role for space science in the context of Third World aspirations. Even though developing countries are particularly interested in the economic and practical benefits of space activity, they are not unaware of the fundamental value of space science:[23]

> It is sometimes argued that basic science in general, and space science in particular, are not important in a world pressed by practical problems. This is not correct. Besides the fundamental argument that an understanding of the universe is important in its own right, it is also true that initiatives in space applications have most often been taken by people who were earlier motivated by their interest in space science.

Space science offers the ability to build the necessary skills and knowledge, the research groups, the facilities—the *infrastructure* for space applications. It also offers a model for the kind of large-scale cooperation with the primary space nations that is needed to build and sustain an applications program. The following "directions to follow" are excerpted (and summarized) from the UN ISPACE Forum report:[24]

1. Obtaining Scientific and Technical Capabilities:
   - Training of scientific/technical personnel by:
     - inviting foreign experts;
     - training in foreign countries; and
     - participating in seminars, conferences, summer study sessions, etc.
   - Such training should be strengthened through locally conducted space experiments (usually cooperative and modest).
   - Training must not be overspecialized. Basic training in electronics, optics, computer sciences, etc., is essential.

[23] Report of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, Aug. 9-12, 1982.

[24] "Relevance of Space Science for Development," in the Conclusions from the UN ISPACE Forum, Vienna, Aug. 4-6, 1982, pp. 2-3.

- Training of high-level scientific and technical teams should be emphasized over training of individual specialties.

2. Fostering International Cooperation:
   - Smaller countries, of modest means, can develop a major space capability only by forming into groups (e.g., ESA, Intercosmos).
   - Developing nations can participate in the space activities of industrialized countries by:
     - — studying data from foreign satellites,
     - – developing their own receiving stations,
     - — participating in balloon or sounding rocket experiments,
     - — participating as guest investigators in foreign projects, and
     - – developing instruments for flight aboard foreign spacecraft.
   - Development of regional space research centers and facilities could provide benefits at a low cost.

Difficulty of Joining the Space Club

One of the expressed motivations underlying U.S. cooperative activities in space is the political one of winning friends and influencing nations. This rationale certainly applies in those areas of the world where the diplomatic balance is less certain than it is among our major allies. Thus, our past cooperative ventures in space science with countries such as India, Pakistan, Peru, and Brazil have a larger significance than their purely scientific content would indicate.

As was noted earlier, because of the great increase in cost of space science projects there is likely to be more cooperation in the future. An increase in cooperative activity in general will make the pressure from the Third World for participation more significant. Competition for cooperative activity as *a po/itica/ tool* is therefore likely to be an increasingly important factor on the world scene. president Reagan's offer in early 1984 to fly an astronaut from the People's Republic of China is certainly a case in point, though subsequent discussion of this possibility has focused on ensuring a substantive science return with space plasma physics as the most likely subject of joint investigation.

Although many developed nations (and ESA) may eschew cooperative arrangements in which the outlay is one-sided—as it will necessarily be in the case of space science—the United States probably cannot afford to overlook the political side of these activities. At the very least, policymakers should be aware of the value of low-level scientific activities in building part of the infrastructure needed for participating in applications, and should make this consideration part of any long-term policy regarding the involvement of developing nations in our space program.

SPACE SCIENCE IN THE 1980s AND 1990s: A VITAL CONCERN

As an enterprise, space science has not had quite the drama of the manned space programs of the 1960s and early 1970s; likewise, the interest in commercialization in space may overshadow its achievements in the public mind. Yet space science has a healthy future. The reaction to the Viking photographs, and especially to the Voyager revelations and IRAS discoveries, showed that there is a lively public fascination with basic discovery in space. The findings of the space telescope may have a similar impact. There is a strong base of public support for space science in the United States, one that will help to preserve this essential undertaking from long-term budgetary decline.

As a foundation for applications in space, space science will continue to be a most useful tool for diplomacy. Space science will also continue to be one of the small drivers of the most advanced elements of our national industry and economy, fueling innovation and growth in many areas. This will be particularly important as private investment in space expands.

Finally, it may be that space science will prove valuable as an offset to military competition in space, providing an outlet for the competition for strength and prestige and, more important, offering a vehicle for cooperation that could once again have a part in some future version of detente.

POLICY OPTIONS

Cooperation With the Soviet Union

As was pointed out earlier in this chapter, the history of Soviet cooperation with the United States in space science has been surprisingly strong. Yet, at any point in this history, the future has always been unpredictable. The United States has traditionally left the door open to cooperation, and the U.S.S.R. has occasionally taken advantage of the invitation. There has generally been little prelude to such initiatives. They are opened by the Soviets on an informal basis, usually through scientific exchange, as global politics appear to permit.

In 1982 the United States decided not to renew the 1972/77 Intergovernmental Agreement, This decision undoubtedly had some of the intended diplomatic impact on the U. S. S. R., but it also eliminated opportunities for U.S. scientists and stifled what had been a fruitful area of international exchange on many levels. At this point, the scientific value of reestablishing that interchange may exceed the political value of continuing to interdict it. Although the political benefits to be gained by cooperating with the Soviets appear relatively small,[25] the scientific benefits of cooperating in certain subfields of space science could be well worth the effort. In the previous agreement, the two primary areas of scientific cooperation were in projects studying space biology and medicine and the Moon, planets, and near-Earth space. Of the two, the most substantive and successful cooperation was in the life sciences.

Scientists actually involved in these exchanges believe that the overall success of the collaborations in life sciences can be attributed to:

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1. a focus on well-defined and specific scientific objectives;
2. the selection of areas of complementary abilities, which provides strong motivations to continue to cooperate once a project is started;
3. the selection of instrumentation that did not raise concerns about technology transfer;
4. institutional organization that gave officials on both sides the autonomy to decide how to implement plans; and
5. the development of mutual confidence, knowledge, and goals among working groups over a long period of cooperation.

[25] *Issues in U.S.-Soviet Cooperation in Space*, Office of Technology Assessment, in press.

In the planetary category, the strongest areas of cooperation were in lunar studies, the exploration of Venus, and solar-terrestrial physics. The exchange of lunar samples and cartographic data provided both sides with a range of information unobtainable by either program alone.

As noted above, however, Public Law 98-562 proposes a limited renewal of U.S./U.S.S.R. cooperation. Such cooperation, if renewed, should be based primarily on the lessons learned from previous cooperative programs,

Project Continuity

From a political standpoint, the most important thing the United States can do to maintain its position of leadership in space science is to provide assurances to cooperative partners that our commitments will be kept. The unilateral decision of the United States to reduce sharply its role in ISPM continues to be mentioned as an example of U.S. unpredictability in cooperative efforts. Assurances may have to take the form of multiyear funding for international missions, so that they are not subject to the vagaries of annual budgeting. Although U.S. political institutions are not structured in such a way as to make multiyear funding generally either particularly desirable or feasible, given the importance of our relationships with our allies, providing multi-year funding for certain specific space projects may be appropriate.

Choosing Specialization

Given the peculiar competitive environment of space science, in which "racing" others for specific accomplishments is counterproductive, competition is likely to take the form of long-term jockeying for areas of specialization (e.g., astronomy, planetary missions). Manned planetary missions (supported by life sciences research) ultimately hold the greatest strategic importance; it is this area that the Soviets appear to be emphasizing. Yet astronomy and astrophysics are perhaps more important to the advancement of related Earth-bound technologies and to the acquisition of knowledge essential to Earth-sensing and meteorological applications.

Technology Transfer

The United States may embark on a program to build long-term infrastructure in space for manned activities.[26] If so, such a program will certainly include some space science research. Many of these space science projects, and indeed, certain components of this infrastructure, may include cooperative efforts with other countries. It will be important for the United States to work out policies governing technology transfer to ensure that we do not give away our competitive edge, while cooperating as fully as possible with others.

[26] *Civilian Space Stations and the U.S. Future in Space* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-STI-241, November 1984).