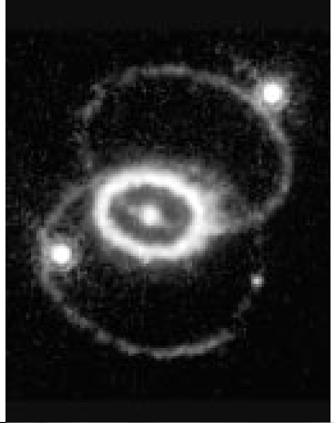
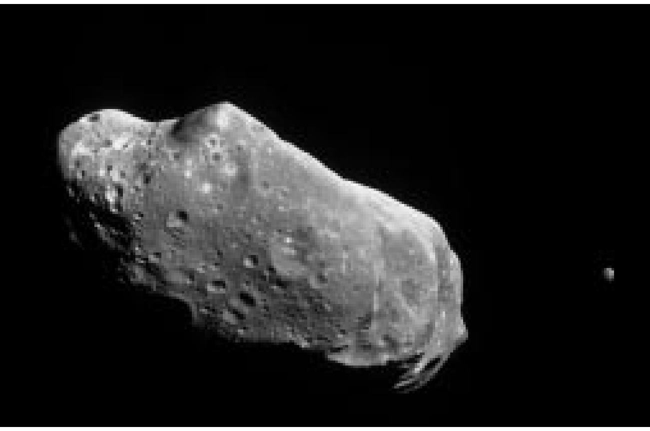
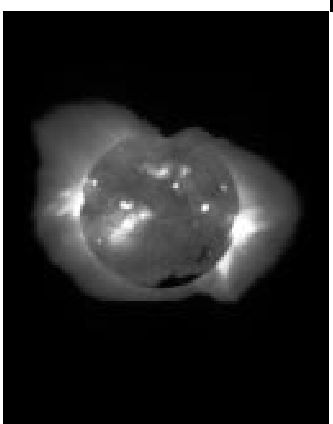
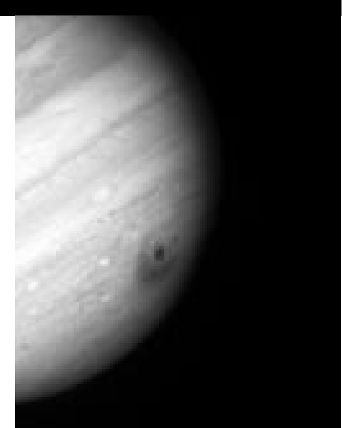


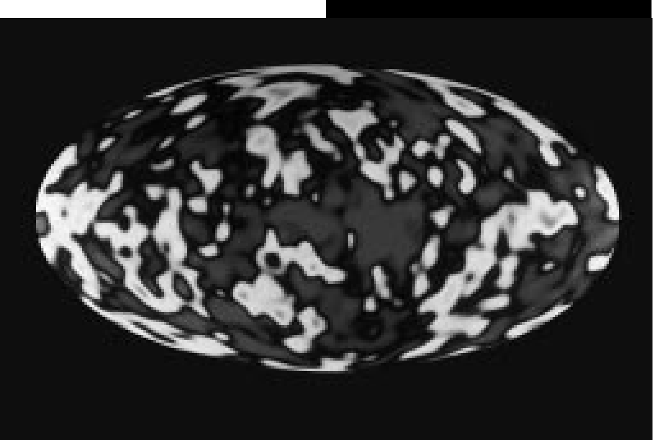


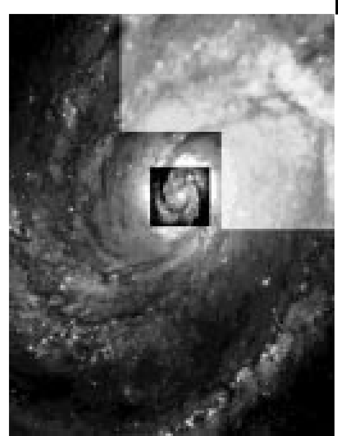
Space Science for the 21st Century

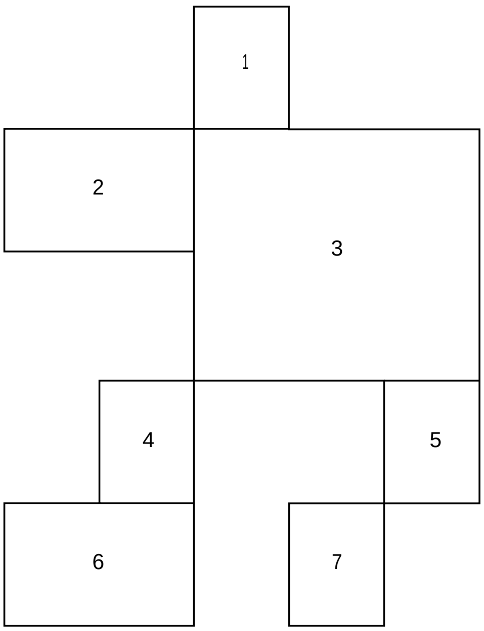


Strategic Plan for 1995-2000
National Aeronautics and Space Administration
Office of Space Science
August 1994









Cover photographs:

1. This striking NASA Hubble Space Telescope picture shows three rings of glowing gas encircling the site of supernova 1987A, a star which exploded in February 1987. Though all of the rings appear inclined to our view (so that they appear to intersect) they are probably in three different planes. The small bright ring lies in a plane containing the supernova, the two larger rings lie in front and behind it. The rings are a surprise because astronomers expected to see, instead, an hourglass shaped bubble of gas being blown into space by the supernova's progenitor star. The supernova is 169,000 light years away in the dwarf galaxy called the Large Magellanic Cloud which can be seen from the southern hemisphere. The image was taken in visible light (hydrogen-alpha emission), with the Wide Field Planetary Camera 2, in February 1994. (NASA/STScI and ESA)
2. About 14 minutes before closest approach to Ida, this image was taken by Gallileo's charge-coupled device (CCD) camera, illustrating the ~37 to 1 size difference between Ida and its moon (far right). Although the satellite appears to be "next" to Ida, it is actually slightly in the foreground. This image, along with the Near-Infrared Mapping Spectrometer data, helped scientists triangulate the bodies to determine that the satellite is about 100 km from the center of Ida. (NASA/JPL)
3. Image of Jupiter obtained with NASA's Hubble Space Telescope's Planetary Camera. Eight impact sites from Comet Shoemaker-Levy are visible. From left to right are the E/F complex (barely visible on the edge of the planet), the star-shaped H site, the impact sites for tiny N, Q1, small Q2, and R, and on the far right limb the D/G complex. The D/G complex also shows extended haze at the edge of the planet. The features rapidly evolved on timescales of days. The smallest features in this image, which is a composite from three filters at 9530, 5550, and 4100 Angstroms, are less than 200 kilometers across. (Hubble Space Telescope Comet Team, and NASA)
4. An X-ray image of the sun taken from the Yohkoh spacecraft on 26 August 1992. Time-lapse movies show that the sun's inner corona is far more dynamic in both structure and brightness than ever imagined, with changes apparent on every temporal and spatial scale. (The solar x-ray images are from the Yohkoh mission of ISAS, Japan. The x-ray telescope was prepared by the Lockheed Palo Alto Research Laboratory, the National Astronomical Observatory of Japan, and the University of Tokyo with the support of NASA and ISAS.)
5. This image of Venus was produced by the Magellan mission using a special radar to see through the planet's clouds and map the surface below. The mosaic combines many consecutive image strips, about 20 km wide, collected from each nearly polar orbit, with less detailed images from the Pioneer Venus Orbiter and Soviet Venera missions to fill some gaps. The view is from above the equator at 180° east longitude. The bright areas usually denote rough surfaces; the dark areas are smooth or possibly covered with dust. (NASA/JPL)
6. COBE DMR — This image represents the first detection of the long-sought spatial anisotropy in the cosmic microwave background radiation, illustrating the origin of structure in the present day universe (COBE Science Working Group).
7. HST M100 — First image obtained of M100 demonstrates the successful optical repair of the Hubble Space Telescope. (NASA/HST)

Space Science for the 21st Century

Strategic Plan for 1995-2000
A Science Plan
accompanied by the
Office of Space Science Integrated Technology Strategy
and the
Office of Space Science Education Plan
(Published Separately)

National Aeronautics
and Space Administration
Office of Space Science

September 1994

Dear Colleague:

I am pleased to release the Office of Space Science (OSS) Science Plan, one of three volumes in *Space Science for the 21st Century*, the OSS Strategic Plan for 1995 - 2000. The other two volumes are the recently released Integrated Technology Strategy and the Education Plan, which is in preparation.

The Science Plan was developed by the Office of Space Science in partnership with the Space Science Advisory Committee. The challenge we faced in developing the Plan is finding ways to start new, high priority science missions in a climate of decreasing budgets. We must ensure the continuation of small, frequent space flight missions while we restructure our proposed larger missions to lower their costs through means such as innovative technologies and international cooperation. We must find ways to use less costly launchers and trim our growing mission operations budgets to free funds to start new missions. Working toward these objectives, we established four themes that describe our present and future programs, and developed a framework and a set of priorities for developing a balanced program.

Space Science is important to NASA and the Nation as the only program that explores beyond Earth orbit and looks outward to the universe beyond the solar system. Space Science produces discoveries and new knowledge, at the same time bringing technological advances in automation, robotics, instrumentation, information technology, and communication. Space Science also has the potential to make major contributions to education.

For Space Science to maintain a continuing pace of new missions and discoveries, and for it to realize its full value to the Nation, we must continue to work with the science community and our implementing institutions to develop more creative ways of doing business. The involvement of decision-makers and the general public will also be vital as we work to implement our Space Science Strategic Plan.

Sincerely,

Wesley T. Huntress, Jr.
Associate Administrator for Space Science

Contents

Space Science for the 21st Century

1. Foundation of the Space Science Program

1.1 Vision

"Space Science explores and seeks to understand the Sun, the Solar System, the Galaxy, and the Universe, for the benefit of humanity."

We humans have a profound and distinguishing imperative to understand our origin, our existence, and our fate. For millennia, we have gazed at the sky, observed the motions of the Sun, Moon, planets, and stars, and wondered about the universe and how we are connected to it.

Throughout history, scientists have revealed many intricate workings of the natural world through remarkable and largely unexpected discoveries. For instance, we now know that the universe was created in the fireball of the Big Bang; that we live in just one of countless galaxies suspended in an expanding universe; and that the particles and atoms of our bodies were created in the Big Bang and forged in the hearts of stars. These are ideas virtually inconceivable to previous generations. Perhaps unimaginable too were the newly revealed vistas of the solar system discovered by recent robotic explorers: rings, volcanoes, and chasms of other worlds awesome in their majesty, complexity, and beauty. Today we are able to gain perspective of Earth through studies of these other worlds, by comparing the effects in different planetary settings of the forces that have molded our environment.

We have also discovered that Earth is immersed in a turbulent solar wind emerging from the Sun's hot upper atmosphere. This wind fills the solar system, creating Earth's radiation belts and comet-shaped magnetosphere. Magnetic storms, driven by solar variability, light up the polar skies and can dramatically affect the function of our communication and power generation systems.

Underlying our quest for knowledge is the desire to understand the basic physical laws that govern the natural world. It is truly remarkable that the physical laws governing Earth appear to apply without modification to the farthest reaches of the observable universe. Our explorations of cosmic phenomena are now permitting us to study and test the uniformity of these physical laws in natural environments far hotter, colder, denser, more tenuous, or larger than any terrestrial laboratory can provide.

1.2 Mission

The mission of the Office of Space Science (OSS) is to seek answers to fundamental questions about:

The Galaxy and the Universe: What is the universe? How did it come into being? How does it work? What is its ultimate fate?

The Connection between the Sun, Earth, and Heliosphere: How does the Sun influence Earth and the rest of the solar system? What causes solar variability?

The Origin and Evolution of Planetary Systems: What was the origin of the Sun, the Earth, and the planets, and how did they evolve? Are there worlds around other stars? What are the ultimate fates of planetary systems?

The Origin and Distribution of Life in the Universe: How did life on Earth arise? Did life arise elsewhere in the universe?

Science strives to find objective answers to these questions through observation, development of theories and hypotheses, experimental tests of new ideas, and discovery.

The primary products of space science are knowledge and discoveries about the universe in which we live and the laws that govern it. Through these products, we bring the benefits of space science to the American public.

The process by which we acquire knowledge and make discoveries is exploration. We explore physically, by means of space probes and planetary landers and orbiters, and we explore remotely, by means of telescopes and other observatories in Earth or heliocentric orbit that observe the Sun, the solar system, and the distant universe.

The American public is not only an investor in space science research, but the ultimate customer and beneficiary as well. The benefits of space exploration to the American public are manifested in several ways including greater *understanding* of the universe, *inspiration* at its wonders, improved *education*, and advances in *technology*.

Understanding and Inspiration: Space science satisfies our desire to understand the solar system and the universe and our place in them. In doing so, it helps provide a perspective that transcends the problems and challenges of daily life and society. Perhaps it can also provide a path for this and future generations to "reach for the stars."

Education: Discoveries and understanding that come from space science missions also feed directly into the educational process. Space science strengthens American education by engaging young people's imagination and stimulating their interest in science and exploration, thereby increasing performance in science and mathematics and leading to a more science- and technology- literate society. Providing educational benefits from its program is an integral part of the activities of OSS.

Technology: The technology development required to carry out space science missions yields new and often unpredictable benefits to American homes and industry. As space science moves toward smaller, less expensive missions, the development of mini- and micro-mechanical and electronic technologies provides many possible avenues for commercial applications. This technology development involves both aerospace and non-aerospace industry. The provision of technological benefits from its program is another integral part of the activities of OSS.

Space science may also benefit the American public and all the people of the Earth in other ways. For example, it may soon be possible to characterize “space weather” and its dependence on the Sun’s variability. Violent “storms,” which can profoundly affect space and Earth-based communication and transportation systems, may soon be predicted by means of Sun and solar wind monitors now under development, coupled with advanced theoretical and empirical models of the coupling of the Sun to the Earth. This and other direct benefits are an important aspect of the value of space science to our Nation and the world.

1.3 Goals

The scope of the mission of OSS is broad. The interrelationships between the origin and evolution of planets, the origin and evolution of stars, the properties of galaxies and the nature of the Sun and the way it interacts with its surroundings are so fundamental and complex that to ignore one aspect is to miss a potentially vital piece of the puzzle. Although the reality of budgets requires us to limit the pace of our inquiry, we choose not to limit its breadth. We must examine the puzzle in its full richness at a pace sustainable with available resources.

The goals of space science are to

- Discover the origin, evolution, and fate of the universe, galaxies, stars, and planets;
- Use the unique environment of space to probe the fundamental laws of physics;
- Understand solar system origin and evolution by exploring, surveying, and sampling the planets and moons with robotic spacecraft;
- Understand and characterize asteroidal, lunar, and planetary resources;
- Determine the processes that drive the Sun and govern its effects on Earth’s environment and the heliosphere;
- Determine if planets, including terrestrial-like planets, exist around other stars;
- Determine if life exists, or ever existed, elsewhere in the solar system and the galaxy;

and to bring home to every person on Earth the experience of exploring space.

1.4 Principles

We strive to embody the values and principles stated here and in the NASA Strategic Plan to better serve the Nation. Our principles include

- Emphasizing excellence as a measure of scientific leadership;
- Maintaining the breadth of our scope of inquiry;
- Emphasizing mission/program designs that maximize the development and dissemination of new technology relevant to broader national needs;
- Pursuing basic scientific goals and strategies defined by the scientific community;
- Accepting mission challenges; attempting that which is hard, not easy;
- Learning from experience; innovating, persevering, and ultimately succeeding;
- Executing programs with imagination, competence, and economy;
- Using broadly representative peer review and advice in all aspects of the program;
- Communicating openly with the science community, industry, Congress, the Administration, other Federal agencies, and the public;
- Nurturing and enhancing the educational process to serve national goals;
- Supporting universities to provide essential long-term research talent;
- Using the best capabilities of industry and NASA Centers effectively in formulating and implementing the space science program;
- Promoting international cooperation, where appropriate, in all our programs;
- Utilizing sound management practices with attention to equal opportunity and diversity, small and small disadvantaged business utilization, and the highest ethical standards of conduct.

2. Program Formulation

2.1 The National Academy of Sciences and OSS Program Planning

The scientific foundation for the space science strategy has been and continues to be developed by the National Academy of Sciences/National Research Council. Since 1958, a number of Academy committees have critically assessed the status of various space science disciplines, identified the most promising directions for future research, outlined the capabilities required to address the most important scientific questions, identified areas where technology development is needed to attain those capabilities, and examined the role of each mission in the context of the total space science program. The space science goals and objectives, and all missions in the past, present, and planned program, can be directly traced to the recommendations NASA has received from the National Academy. (A representative list of reports and other relevant Academy studies is contained in Appendix E.)

In developing its program and mission strategy, OSS has, in turn, examined the Academy's recommendations, usually studied a number of options for obtaining the measurements required to address the prime scientific questions, and arrived at a set of specific missions intended to respond to the Academy's scientific strategies. The formulation and development of these missions has been monitored by the Space Science Advisory Committee, its three Subcommittees, and numerous Science Working Groups whose memberships are drawn largely from the non-NASA science community. The individual missions are also periodically reviewed by the Academy to ensure that they are responsive to Academy recommendations. This process ensures that space science missions meet the highest scientific standards and contribute to an overall strategy for scientific advancement with adherence to carefully considered priorities.

2.2 Structural Elements

The scientific process involves a chain of events that begins with defining specific scientific questions based on experiment, theory, and/or data analysis; designing and conducting experiments to address these questions; analyzing, interpreting and disseminating the results of these experiments; and finally, using the new knowledge to frame new scientific questions. Each space science program element—the Research Program; Flight Mission Development; and Mission Operations and Data Analysis (MO&DA)—plays a unique and vital role in the process. The relationship between these elements and the scientific process is illustrated in Figure 1.

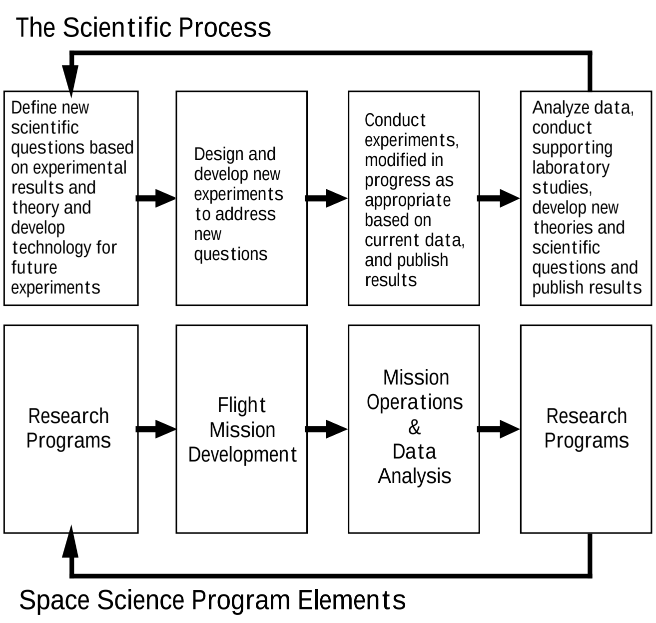


Figure 1. OSS Structural Elements Mirror the Scientific Process

The first element, the *Research Program*, has two major functions. The first function is to support the analysis and interpretation of results from past missions, as well as data from related airborne, suborbital, and laboratory studies. This is accomplished through advanced information systems, which are essential to achieving our scientific objectives. This research yields the scientific questions that form the foundation of subsequent missions. The second function is to support the development of new technologies, information systems, and mission design concepts that prepare us to initiate new flight development projects.

The second element, *Flight Mission Development*, includes detailed mission definition; spacecraft and instrument design, development, testing, and integration; and launch support.

The third element, *MO&DA*, supports the operation of missions following launch and the analysis of data during the mission's operational lifetime. The Data Analysis component of this element is essential for evaluating the quality of the returned data, utilizing the capabilities of our spacecraft to capitalize on current discoveries and insights, and providing the first scientific returns from our missions.

Finally, the results of flight missions are published and disseminated, as well as incorporated into the Research Program for detailed analysis, comparison, and amplification through other research tools. This understanding and progress complete the cycle of the scientific process, paving the way for future inquiry and experiment.

2.3 Current Program

OSS programs are centered around four themes, which correspond to the fundamental intellectual questions we seek to answer.

The Galaxy and the Universe: How did structure evolve from chaos? How did galaxies evolve, and what triggers the formation of stars? How are stars born, how do they die, and what are the consequences of their deaths? Are the fundamental laws of physics invariant throughout the universe?

Sun-Earth-Heliosphere Connection: What is responsible for the variability of the Sun, a typical star, on all time scales? How do the magnetic field regions and uppermost atmospheres of the planets, especially Earth, respond to variations in solar radiation and solar wind? What drives the solar wind and the dynamic interplanetary environment? What governs the origin and acceleration of solar and galactic cosmic rays? What governs their propagation through the solar system?

Planetary System Origin and Evolution: How are the characteristics of different planets related? What processes shape the natures of planets? Which processes are currently taking place? What can we learn about Earth by studying other planetary bodies? Are there terrestrial-like planets around other stars?

Origin and Distribution of Life in the Universe: What generated the conditions for life on Earth? Was there ever life elsewhere in the solar system? Is there life elsewhere in the universe?

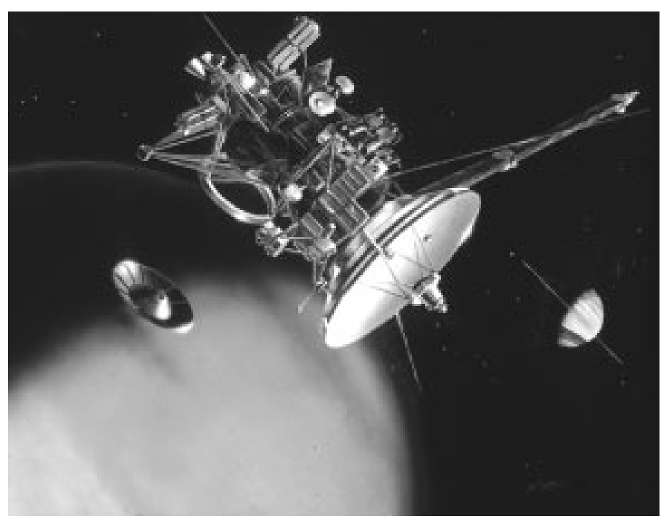
The current OSS program (see Figure 2) represents a major, long-term, multi-billion dollar investment in space science by the U.S. taxpayers, a series of Administrations, and the Congress. That investment has produced a veritable treasure trove of scientific assets whose output has literally rewritten the textbooks in many fields of science.

A small sample of the many scientific accomplishments that are now flowing from the current program includes:

Space Science	Flight Programs	
	Ongoing	In Development
Galaxy & the Universe	HST CGRO EUVE KAO (Voyager)	AXAF GP-B SWAS XTE FUSE
Sun-Earth-Heliosphere Connection	SAMPEX Ulysses Yohkoh Voyager (CGRO)	ACE GGS FAST SOHO
Planetary Origin & Evolution	Galileo (KAO, HST)	Cassini NEAR Mars Pathfinder
Origin & Distribution of Life in the Universe	(Galileo, KAO)	(SWAS, Cassini, Mars Pathfinder)

Figure 2. The Current Space Science Program. Missions appear without parentheses under the themes they primarily address. Some appear again with parentheses under a theme that is their secondary objective. International missions in which NASA has a major involvement are included. Acronyms are defined in Appendix A.

- The first two Great Observatories, the Hubble Space Telescope (HST) and the Compton Gamma Ray Observatory (CGRO), are both fully operational. The numerous, major scientific discoveries from these two space observatories are revolutionizing our understanding of the universe.
- The face of Venus has been revealed at high resolution for the first time by the Magellan spacecraft. More than 99 percent of the surface of this perpetually cloud-covered planet has been mapped at 120-meter resolution by radar.
- The joint European Space Agency/NASA Ulysses solar spacecraft has begun its passage over the Sun's south pole, with north polar passage to follow next summer, exploring one of the remaining frontiers of the Solar System.
- The Cosmic Background Explorer (COBE) spacecraft has confirmed the big-bang theory of the origin of the universe and has revealed structure in the remnant radiation that explains the birth of galaxies in the early universe.
- The Galileo spacecraft has conducted the first-ever asteroid flybys of Gaspra and Ida, discovering the moon of Ida, and is now on its way to a rendezvous with Jupiter in December 1995.
- The Extreme Ultraviolet Explorer (EUVE) has revealed large anisotropies in the hot interstellar medium in the Sun's vicinity, allowing even extragalactic extreme ultraviolet sources to be observed.
- X-ray studies of the solar corona by the joint Japan/U.S. Yohkoh mission have revealed continuous violent activity—a vivid contrast to the subtle visible luminosity variations on the underlying disk of the Sun.
- Ground-based observational work continues to add sig-



Artist's conception of the Cassini Orbiter and Probe. (NASA/JPL) nificant value to the OSS program. Recent highlights include the discovery of Comet Shoemaker-Levy and observations of the spectacular impacts of its fragments with Jupiter in July 1994, as well as radar observations of 4769 Castalia, a "double" near-Earth asteroid. The comet impacts were also recorded by instruments on the Galileo spacecraft, as well as a variety of other platforms, including the Hubble Space Telescope and the Kuiper Airborne Observatory.

3. Responding to the Changing Environment

3.1 Changing Environment

The budget climate within which the space science program is planned has changed drastically over the last several years. The period from fiscal years 1986 through 1991 was one of double-digit annual growth for NASA as a whole, and space science maintained a relatively constant proportion of the NASA budget. The major missions currently under development were approved during this period. The period from fiscal years 1992 to 1994 has been one of transition, in which earlier expectations of growth that formed the basis for program planning were not realized. The consequences were dramatic: approved programs were canceled or drastically restructured, losses were experienced in supporting programs, and plans for new missions were not realized. The period beginning with the FY1995 budget, which is the period addressed in this plan, is likely to be characterized by flat or declining budgets for space science.

Along with the budget decline, there has been a shift in emphasis in national priorities. Concern over America's economic vitality and competitiveness has led to a focus on the economy and related areas, such as education and technology development. NASA is being called upon to emphasize the contributions it can make in these areas as a more direct contribution to the well-being of all Americans.

A number of steps have already been taken to respond to the changing fiscal and national environment. For example:

- Cassini was restructured to significantly reduce the peak funding requirements and life-cycle cost of the mission by simplifying the spacecraft, reducing mission operations costs, and trimming science requirements. Although the full breadth of Cassini science was maintained, some depth was sacrificed.
- Advanced X-Ray Astrophysics Facility (AXAF)—the third of the Great Observatories—was restructured to reduce peak funding requirements and life-cycle cost by dividing the original mission into two smaller, lower cost missions: an imaging mission (AXAF-I), and a spectroscopy mission (AXAF-S, which was subsequently canceled), and operations costs were reduced by eliminating on-orbit servicing of the spacecraft and planning for a shorter operational lifetime.
- The single large spacecraft concept was abandoned for the program designed to recover the lost Mars Observer science objectives. The new proposed Mars Surveyor Program provides a more robust approach, distributing risk with two launches per opportunity using small orbiters to recover global orbital survey objectives and an evolutionary series of small, inexpensive landers to meet landed science objectives.

The changing environment has led us not only to restructure programs in development, but also to fundamentally alter our approach to future missions. With expectations of flat or declining budgets, we have redirected planning toward smaller, less expensive projects requiring shorter development times. Two current examples are the Small Explorers Program, initiated in 1989 to carry out surveys and focused science studies in astrophysics and space physics, and the Discovery Program, initiated in 1993 to carry out small, focused solar system exploration missions.

Quality inspectors perform a visual inspection of the P1 (Parabola 1) optic for NASA's Advanced X-ray Astrophysics Facility (AXAF). P1 measures 1.2 meters in diameter by 1 meter in length and weighs 520 pounds. The wall of the optic is only nine tenths of an inch thick. All eight AXAF mirrors will be completed by Spring 1995; an end-to-end x-ray test of AXAF will be conducted starting in January 1997. (Hughes-Danbury Optical Systems)

The trend for future programs is also toward smaller, less costly missions that can still accomplish "world class" science. Specific actions that we will take to move in this direction are outlined in the following section and in Section 4.

3.2 Strategic Actions

To accomplish our goals in an era of level or declining budgets, we must dramatically reduce costs. In terms of a cost-performance curve, there are two approaches (Figure 3). "Moving down the curve" will relegate us to ever-decreasing levels of performance. "Creating a new curve" for which a given performance level can be achieved at lower cost is imperative if we are to meet the scientific challenges of the future.

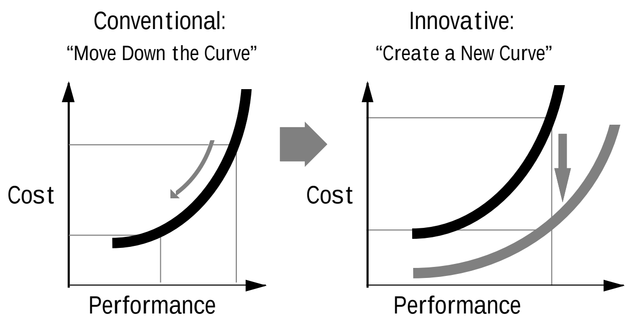


Figure 3. Creating a New Cost-Performance Curve

Many actions will be necessary to create and realize the benefits of a new cost-performance curve. Some have already been initiated, and others must be added. We must explore new conceptual approaches to missions, streamline management, introduce new technologies, and increase investment in mission definition prior to development. The following specific strategic actions will contribute toward the creation of a new cost-performance curve, and, in doing so, will free resources for application to future programs.

Reduce the costs of missions in development.

Cassini and AXAF have been successfully restructured to reduce both life-cycle cost and peak-year spending while maintaining major mission goals. We are establishing cost caps for all other missions in development consistent with new NASA policy. A primary objective is minimizing life-cycle costs in all our programs.

Reduce the costs of operating missions.

Savings have been achieved over the past 2 years by re-engineering mission operations. Efficiencies and new, innovative approaches to mission operations will be continually sought in order to free resources for new future missions. Among the actions being taken and/or examined are:

- Streamlined, paperless procedures for operations planning;
- Consolidation of control and data handling centers to achieve efficiencies through shared equipment, software, and expertise;
- Use of common software and hardware beginning with mission development and integration and continuing during flight operations; and
- Applications of new technologies to achieve more autonomous, less labor-intensive operations.

Furthermore, all missions in the extended phase of their operation will be reviewed for science productivity and prioritized each year in competition with new starts so that maximum science benefit can be achieved with limited resources.

Continue to direct the definition of new flight programs to smaller, less costly missions.

We will focus new mission studies on less costly options, define cost as a significant constraint early in mission definition, and more precisely define mission science objectives so as to contain costs. An ensemble of low-cost missions can be phased to fit into a stable level-of-effort budget without the large funding spikes characteristic of large missions. We will also renew our emphasis on looking for opportunities to collaborate with other agencies and international partners to reduce costs and avoid duplication, and we will search for lower cost launch options wherever possible.

Provide for continuing investment in technologies for future missions.

One approach to doing more science for less cost is to use off-the-shelf technologies. This short-term approach leads to rapid technological obsolescence. Rather, we must foster the use of new technologies through a program that prepares them for flight. NASA and industry are collaborating to ensure the rapid development and availability of technologies for NASA and other agencies. The resulting capability will reduce launch costs through the reduction of spacecraft mass, and the total life-cycle costs through enhanced effectiveness. A number of ancillary benefits will also be derived.

The first element of the strategy is a customer-oriented focus in NASA's technology office. The pathway to flight begins with implementation of a broad-based, but mission-focused, technology development program that meets the needs of its users. The goal is to increase capability and minimize risk by early investment in the critical technologies needed for each mission. These investments will usually result in "protoflight" hardware or software that can be taken to the next step—qualification in a flight system testbed.

The second element is a joint effort by both NASA's technology office and OSS to establish flight system testbeds at NASA flight centers. These testbeds will provide a "virtual spacecraft environment" for developing new subsystem prototypes.

The third element is the provision of flight opportunities for prototype subsystems and instruments. This can be accomplished through "payloads of opportunity" on science missions, dedicated engineering flights, or balloons and sounding rockets.

The new space science technology policy requires that each mission contribute to the advancement of space flight technology to ensure the continuing availability of new technologies for future missions. The policy will ensure that NASA space science missions resume a role in driving the technology engine of the U.S. and thus contribute to the economic competitiveness of the nation.

Seek international cooperation on new flight programs.

The space science enterprise is now more than 35 years old, and since its very beginnings has been pursued as an international enterprise. The last 15 years have seen an increasing level of international cooperation on U.S. missions in the form of the participation of foreign scientists, the accommodation of scientific instruments or subsystems, the provision of tracking and navigation services, and provision of launch services. Similarly, U.S. scientists and U.S. provided instruments and services have been playing an increasingly important role on non-U.S. missions. Some missions, such as Cassini and Solar and Heliospheric Observatory (SOHO) have been carried out as joint projects. This latter style of cooperation will become ever more common as the worldwide resources available for space science become more scarce.

OSS will pursue international participation to enable missions that otherwise might not be possible, to avoid duplication, to add science value, and to share cost with international partners. Examples of opportunities for future international cooperation include SOFIA, a proposed infrared astronomy cooperative program with Germany; Astro-E, an X-ray astronomy mission by Japan's Institute for Space and Astronautical Science; and Rosetta, a European Space Agency comet rendezvous mission. In the case of Astro-E, NASA is taking advantage of an opportunity to achieve many of the spectroscopy objectives that had been planned for AXAF-S. In the case of Rosetta, NASA is investigating enhancing the mission through the addition of one or more international science landers for which NASA would lead the development. NASA may also contribute instruments and engineering subsystems for the Rosetta comet orbiter.

Strengthen the Research Program.

As noted earlier, the Research Program in space science provides support for the science community to analyze and interpret results of past missions, as well as data from related airborne, suborbital, laboratory and theoretical studies. It also supports the development of new technologies, information systems, and mission design concepts. Thus, the Research Program delivers the ultimate products of space science and exploration and helps set the stage for the future. The Research Program is therefore an absolutely central element forming the foundation for virtually everything that OSS does. However, it must evolve to match our mission strategy. In a flat budget environment, difficult choices must be made in funding Research Programs in order to make room for new results, new subdisciplines, and new initiatives.

Work to secure a stable budget environment.

Our efforts to reduce development and operations costs will help sustain a viable program within an increasingly constrained resource envelope. However, we can be successful in implementing such a program only if we can secure a stable budget. Although many of the factors that determine the overall fiscal environment are not in our control, a number of steps that we can take to secure a healthy future are in our control. In particular, we can

- Be selective in determining our objectives;
- Deliver on the promises we make, and successfully bring our programs to completion;
- Provide for broad, timely dissemination of our results in an understandable form;
- Use public interest in our program to foster a scientific and technologically literate society;
- Make demonstrable contributions to the advancement of technology; and
- Demonstrate to the science community, the public, and government decision-makers that our programs are both relevant and important.

4. Strategy

4.1 Near-Term Objectives

Our objectives for the remaining years of this century, grouped by theme, are listed below.

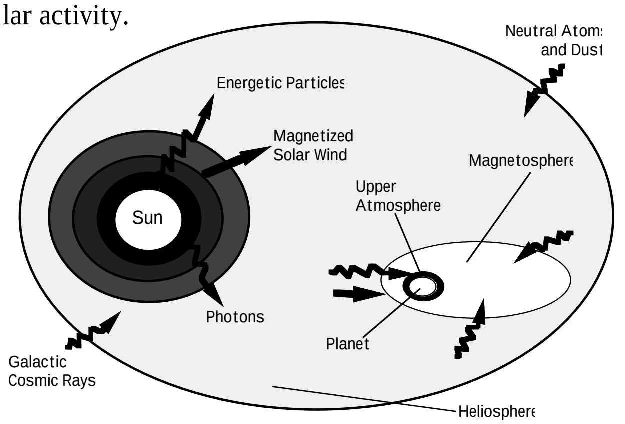
The Galaxy and the Universe

- Complete development of the means to survey the universe across the entire electromagnetic spectrum.
- Complete the survey of cosmic rays through their highest energies, and of interstellar gas, both unique samples of matter from outside the solar system.
- Carry out a basic new test of the Theory of General Relativity.

The hundreds of galaxies seen in a single image from HST exemplify the data that astronomers can obtain to determine the structure and evolution of the universe.

Sun-Earth-Heliosphere Connection

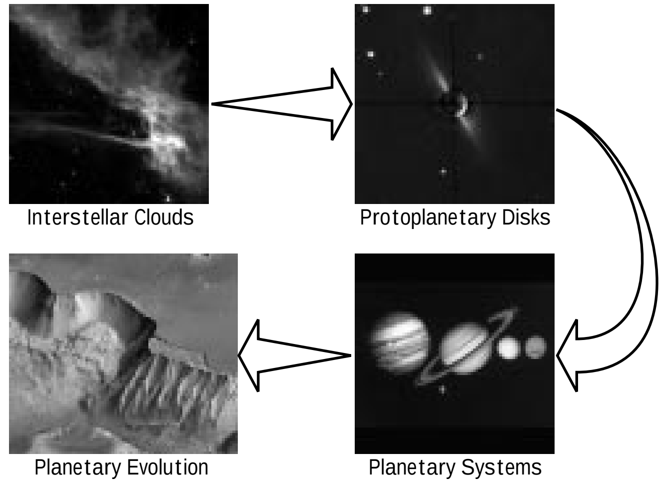
- Complete development of the means to understand the mechanisms of solar variability and its effects on Earth.
- Complete the first exploration of the inner and outer frontiers of the heliosphere.
- Determine the plasma environments of the solar system planets and how those environments are affected by solar activity.



The Sun, itself a subject of intense study as our nearest star, creates and drives many solar system phenomena through its outputs of electromagnetic energy, energetic particles, and solar wind. These outputs affect Earth's magnetosphere, ionosphere, and uppermost terrestrial atmosphere. The solar wind itself carves out a huge bubble in interstellar space called the heliosphere. Cosmic rays as well as neutral atoms and dust are constantly entering the solar system by crossing the boundary of the heliosphere, carrying information about our galaxy and universe even as they undergo alterations in their encounter with the Sun's outflow of mass and energy.

Planetary System Origin and Evolution

- Complete development of the means to finish the reconnaissance of the entire solar system from the Sun to Pluto.
- Begin the comprehensive search for other planets, including habitable planets like our own, around other stars.
- Resume surface exploration of solar system bodies to understand the origin and evolution of the Sun's planetary system.



Planet formation probably begins with the gravitational collapse of a dense cloud of gas and dust. A central protostar forms, but initially is not visible from the outside. As it gathers material, it shrinks and later becomes a "sun." Material that does not fall on the protostar forms a disk in the equatorial plane and begins to clump together and form planetesimals. The example shows circumstellar material surrounding the star, beta Pictoris. The planetesimals accumulate to become terrestrial planets and the cores of giant planets. The residual gas and dust dissipate, either blown away by stellar winds or accreted onto the planets that remain. Processes alter the characteristics of the primordial bodies as shown in this example of landslides within Mars' Valles Marineris.

Origin and Distribution of Life in the Universe

- Continue the study of biogenic compounds and their evolution in the universe.
- Search for indicators of past and present conditions conducive to life.

The central figure shows chemical evolution progressing from simple chemicals, to DNA, to microorganisms. On early Earth, this progression from primordial compounds to life could have been enabled by lightning, hydrothermal vents, and/or cometary impacts. We think this process is intrinsically connected to planetary evolution and is common in the universe. (Composite NASA and Scientific American 2/91. Adapted from "In the Beginning…" by John Horgan. ©1991 by Scientific American, Inc. All rights reserved.)

Space Science	Flight Programs		
	Ongoing	In Development	Future
Galaxy & the Universe	HST CGRO EUVE KAO (Voyager)	AXAF GP-B SWAS XTE FUSE	SOFIA SIRTF Explorers* (Solar Probe)
Sun-Earth-Heliosphere Connection	SAMPEX Ulysses Yohkoh Voyager (CGRO)	ACE GGS FAST SOHO	Solar-Terrestrial Probes Solar Probe Explorers*
Planetary Origin & Evolution	Galileo (KAO, HST)	Cassini NEAR Mars Pathfinder	Mars Surveyor Discovery Missions Pluto Fast Flyby (SOFIA, SIRTF)
Origin & Distribution of Life in the Universe	(Galileo, KAO)	(SWAS, Cassini, Mars Pathfinder)	(Mars Surveyor, Discovery Missions SOFIA, SIRTF)

* Future Explorers are a continuation, using small spacecraft, of the Explorer series of missions represented in the ongoing and in-development flight programs.

Figure 4. Current and Future Space Science Program. Missions appear without parentheses under the themes they primarily address. Some appear again with parentheses under a theme that is their secondary objective. Acronyms are defined in Appendix A.

4.2 Future Programs

As discussed in Section 3, declining budget expectations for space science require that we fundamentally alter our approach to future missions. Individual spacecraft have been made smaller to reduce spacecraft development as well as launch costs. Mission operations procedures are being critically reevaluated. Large spacecraft have been broken into multiple small spacecraft to distribute risk and reduce cost. The introduction of new technologies has been made an integral part of all future programs. Heightened attention is being paid to the broad dissemination of those technologies, and to identifying and developing educational opportunities associated with all missions.

Scientifically, the future program is designed to make significant advances across all four themes.

4.2.1 The Galaxy and the Universe

Ongoing flight programs such as Hubble Space Telescope and Compton Gamma Ray Observatory are now providing extraordinary discoveries. Adding the Advanced X-ray Astrophysics Facility (AXAF) and the other missions in development will provide access to other unexplored phenomena.

The remaining wavelength window on the universe to be exploited from space is the infrared. It has come last because detector development was more challenging, but that development is now well advanced. The importance of completing a full picture of the universe is so great that the only priority in this theme is to undertake missions in infrared astrophysics. Two programs are proposed: the Stratospheric Observatory for Infrared Astronomy (SOFIA) and the Space Infrared Telescope Facility (SIRTF).

The Stratospheric Observatory for Infrared Astronomy (SOFIA) represents a major increase in capabilities over the highly successful, but aging Kuiper Airborne Observatory (KAO). SOFIA will be used to study star and planet formation, the dynamics and chemistry of the interstellar medium, galactic structure and evolution, and the Sun and other so-

SOFIA will directly involve K-12 teachers and students with scientists and engineers through a series of meaningful educational partnerships, stimulating interest in mathematics, science and engineering. (NASA Ames Research Center)

lar system bodies. The mission consists of a 2.5-meter infrared/submillimeter telescope that will be installed in a modified Boeing 747 aircraft and operated at altitudes above 40,000 feet. During operations, the telescope port will be open and exposed to the environment, while scientists will work in a shirt-sleeve pressurized environment. SOFIA is expected to carry out 160 eight-hour research flights per year over a 20-year lifetime. In addition to increased sensitivity, SOFIA will provide a threefold increase in spatial resolution over the KAO.

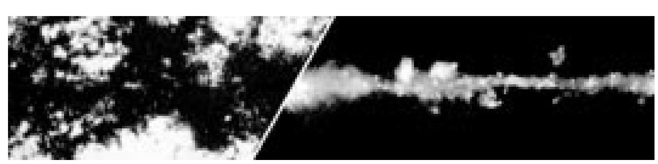
Because of its mobility and the fact that nonspecialists can fly on a SOFIA mission, it will be the only NASA program in which educators can actively participate as flight members with scientists and engineers. This will build on the highly successful, beneficial experience that many K-12 teachers have had on the KAO. Furthermore, SOFIA's ready access as an airborne platform and its operational flexibility will allow it to serve as a testbed for development of new instrumentation and aeronautics technologies.

Several innovative steps have been taken to reduce the SOFIA program cost. First, a major collaboration is planned in which the German Space Agency would provide the telescope and its mounting assembly. The NASA portion of this program—purchase and modification of the aircraft, integration of the telescope into the aircraft, and provision of the airborne mission control center and ground support facilities—will be done in a quick and less costly manner through a combination of innovative technical approaches, improved management efficiencies, and reduced costs through the purchase of a used aircraft. By taking these steps, and grounding the ongoing Kuiper Airborne Observatory to free up its operations funds, SOFIA can be accomplished for less than $150 M (FY94 dollars) in new cost. Our goal is to commence the operation of SOFIA by the year 2000.

The Space Infrared Telescope Facility (SIRTF) will take advantage of recent spectacular advances in infrared sensor technology to build on the technical heritage of two of space science's most successful missions, the Infrared Astronomical Satellite (IRAS) and the Cosmic Background Explorer (COBE). The SIRTF mission has been vastly simplified from its original design through a focusing of its scientific objectives and the use of innovative design techniques. This has resulted in significant reductions in lifecycle cost. Examples of the innovative approaches to implementing SIRTF include the use of a "warm launch," which removes the requirement to encase the entire telescope in a dewar, and use of a solar orbit, which reduces requirements on the cryogenic system while preserving lifetime. By exploiting extraordinary advances in detector technology, SIRTF can still address the fundamental scientific objectives that make this mission so critical to modern astronomy, even though it will have a mass smaller than IRAS.

Current plans call for SIRTF to be developed for a cost below $400M (FY94 dollars) and to be launched on a Delta 7920 rocket into solar orbit. SIRTF is planned to be operated for 2.5 years.

SIRTF and SOFIA are complementary programs. Both are essential for exploiting the infrared region of the spectrum. The SOFIA science program will capitalize on spatial and spectral resolution, for example in studies of protostars, and on mobility, which permits optimum observation of transient events such as comets, eclipses, and novae. The SIRTF science goals make use of its excellent sensitivity and large detector arrays, for example to search for faint galaxies forming at the edge of the visible universe. Conversely, SOFIA's targets tend to be galactic objects or nearby galaxies that may be studied with spatial and/or spectroscopic detail not possible with SIRTF.



Optical Infrared

SIRTF will be able to peer through the dust in our galaxy, providing us with a view of the center that would otherwise be unavailable. (Infrared Processing and Analysis Center)

4.2.2 Sun - Earth - Heliosphere Connection

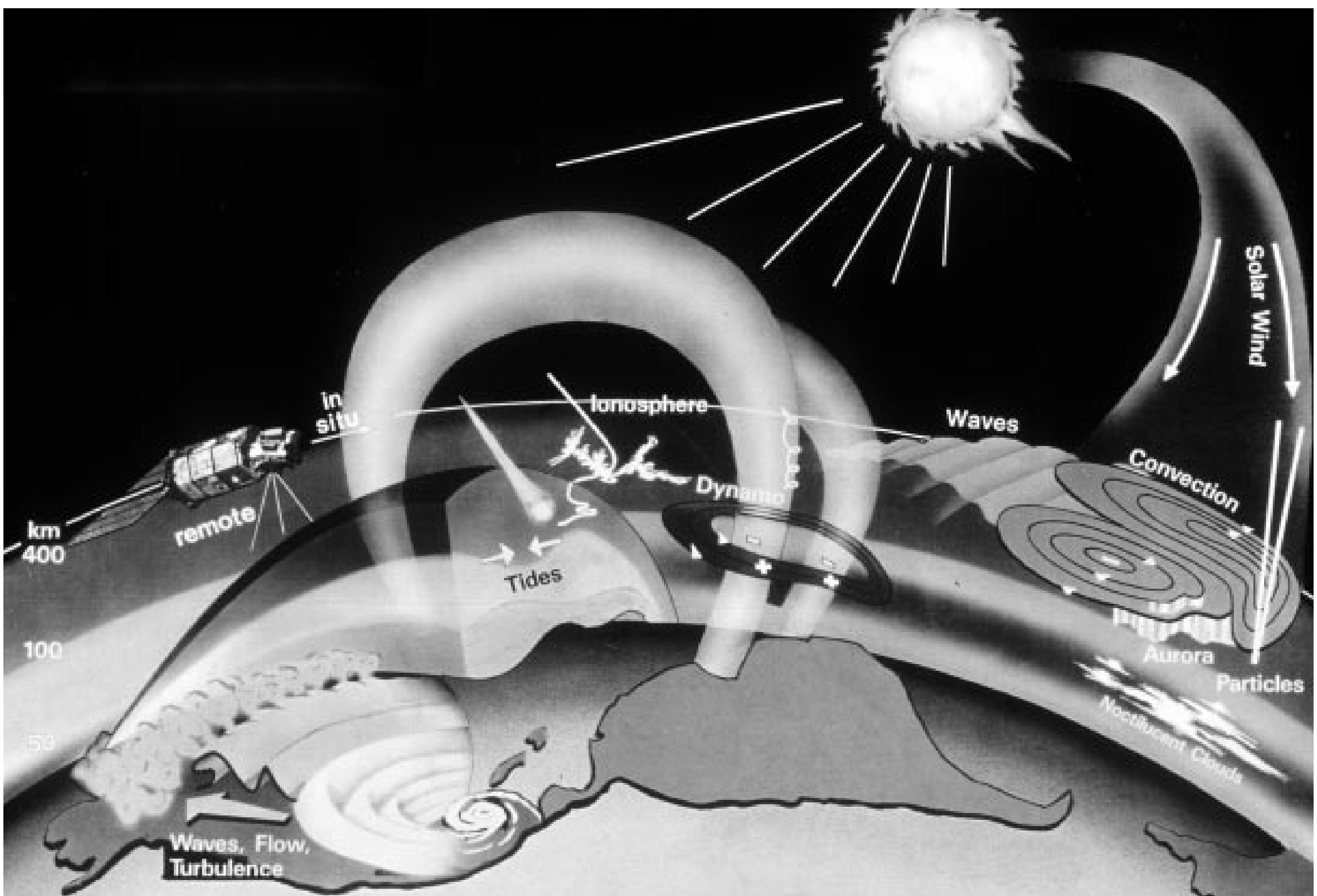
Scientific progress in this thematic area exploits existing spacecraft already in orbit about the Earth and Sun along with a limited number of new small, high-technology spacecraft (the new Solar Terrestrial Probe series), the opportunity to participate in or obtain data from international missions, and a new Solar Probe mission.

The Solar Terrestrial Probe series will employ small spacecraft (typically costing less than $100M for spacecraft and instruments) for highly focused studies addressing critical problems in solar variability and its influences. The objective is the achievement of cutting-edge science at low unit cost per mission through utilization of innovative instrumentation; small spacecraft incorporating state-of-the-art technology; small launch vehicles; partnerships between the university community, industry, and NASA in tightly organized teams; and low cost mission operations techniques.

The planned program will use Solar Terrestrial Probes to study three critical types of Sun-Earth-Heliosphere connections:

The Low Energy Radiation Connection: An investigation of the connection between the variable ultraviolet (UV) and extreme ultraviolet (EUV) radiation from the Sun and the response of the Earth's mesosphere/lower thermosphere—the outermost layer of the Earth's atmosphere. A single small satellite, the Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) mission will measure the variability of the UV/EUV output of the Sun and use remote sensing techniques to probe the response of the mesosphere and lower thermosphere, over the altitude range from 60 to 180 km.

The High Energy Radiation Connection: An investigation of the generation of solar high energy radiation and particles in flares. A small satellite called the High Energy Solar Imager (HESI) will use innovative technology to obtain images at wavelengths from x-rays to gamma-rays, the highest energies released in flares. It is critical that HESI be operating during the period of maximum solar activity expected in 1999-2002. This mission is expected to fill in the heretofore critically missing observational boundary conditions that will allow discrimination among the competing flare theories.

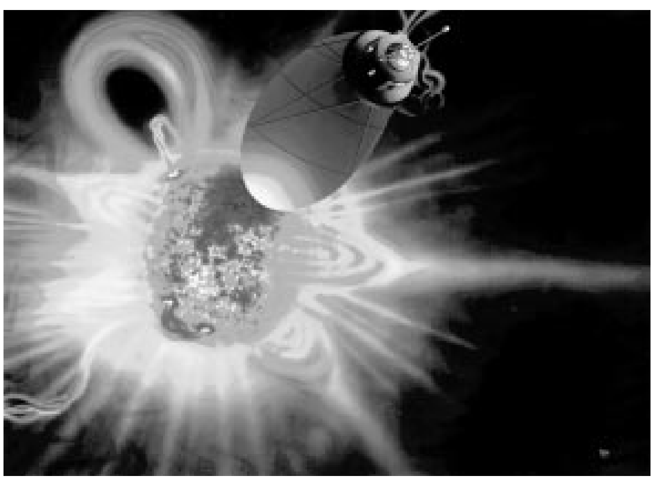


The TIMED mission will investigate the energy input/output and the dynamics of the mesosphere and lower thermosphere. (NASA/GSFC)

The Plasma Connection: An investigation of the connection between the mass (plasma) ejections from the Sun and the global response (geomagnetic storms) of the magnetosphere. The Magnetospheric Imager (MI) will use innovative techniques to make the first images of Earth's magnetosphere in both ultraviolet photons and particles (energetic neutral atoms). This will be the first direct view of the dynamically evolving magnetosphere in which Earth satellites operate. The variable input of solar plasma to the magnetosphere will be measured by the Advanced Composition Explorer (ACE) spacecraft currently under development for launch in late 1997.

Solar Probe will be our initial close reconnaissance mission to the largest unexplored solar system body, namely, the Sun itself. Just as the Voyager spacecraft returned stunning new scientific insights about the outer planets, Solar Probe will be a voyage of discovery to the center of our solar system. Passing within 3 solar radii of the Sun's surface, this mission will address long-standing, fundamental questions about the connection of the solar corona to the outflowing solar wind that fills the heliosphere. These questions include "What heats the solar corona?" "What accelerates the solar wind?" "Where does the solar wind come from?" and "What mechanisms accelerate, store, and transport energetic particles?"

As currently envisaged, Solar Probe will consist of lightweight spacecraft launched by Delta rockets onto direct trajectories to Jupiter, where gravity assist maneuvers will place them on their Sun-grazing trajectories. These new technology spacecraft will achieve their low mass by combining the thermal shield and high gain antenna into a single unit, and by incorporating the latest industrial high-technology systems.

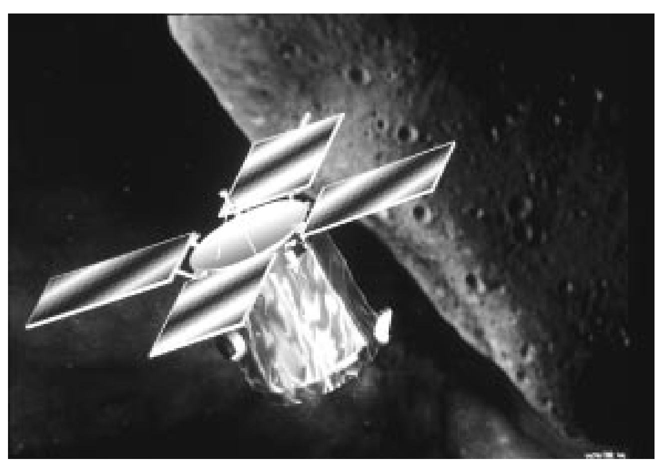


Because the Solar Probe mission will fly within 3 solar radii of the Sun's surface (about 70 times closer to the Sun than the Earth), a large thermal shield must shade the instrument payload. The spacecraft does not overheat since it flies by the Sun in about one day. The shield also serves as the antenna to transmit the science data back to Earth. Such a close fly-by of the Sun has never been accomplished and is the only way certain critical problems in solar science can be studied. (NASA/JPL)

4.2.3 Planetary System Origin and Evolution

Planning for missions to study our planetary system has undergone a dramatic restructuring, from an earlier emphasis on comprehensive, but large and infrequent missions, to a current emphasis on frequent, small, focused, low-cost missions using small launchers. The future programs proposed for this theme maintain the highest level of scientific quality using small, innovative spacecraft.

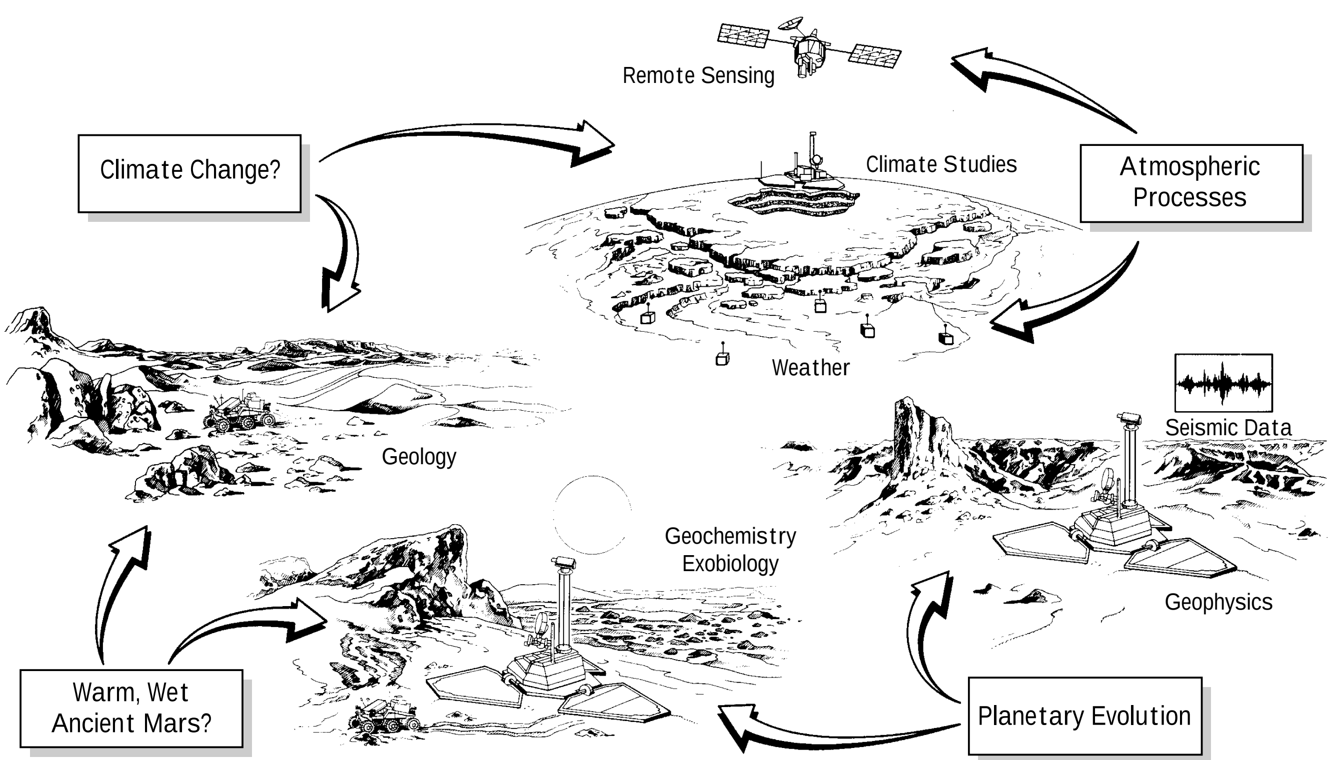
The Discovery Program responds to NASA and Congressional imperatives to develop small, low-cost planetary missions that can be built and flown by the science community in a very short time span (3 years or less from New Start to launch). Discovery will provide frequent access to space to address focused science objectives and opportunities to explore emerging planetary science disciplines. It will also provide opportunities for university and student involvement and for new technology infusion and transfer that cannot be attained in larger and lengthier programs. Although the stringent cost cap ($150 million in FY1992 dollars) of Discovery missions limits their objectives, the great potential of the program for innovation and breakthrough discoveries is exemplified by the range of concepts which have been studied. These include missions to Mercury, Venus, Mars, comets, and asteroids, as well as Earth-orbiting telescopes, solar wind sample return, and small probes to the outer solar system. The Discovery Program will stimulate innovative teaming and management ap-



Artist's concept of the Near Earth Rendezvous (NEAR) Spacecraft. (NASA/APL) proaches among industry, university, and government partners. The Discovery Program is a new paradigm for a sustained program of low-cost, high-flight-rate planetary missions.

The Mars Surveyor Program is a small-spacecraft, innovative approach to both recovering from the tragic loss of Mars Observer and resuming the surface exploration of Mars. It is a vital step toward our long-range goals for Mars exploration: to determine whether life ever began on Mars, and if so in what form; to better understand the climate history of the planet; and to determine the mode of formation and evolution of the solid planet. The flight program is a level-of-effort activity that includes two launches of orbiters and landers at each opportunity (1996, 1998, 2001, etc.) in a progression of focused missions for orbital, landed, and sample return science investigations. The orbital missions will provide detailed global reconnaissance measurements from low circular orbits. The first of these will carry three-fourths of the Mars Observer science instruments with only one-third of the total spacecraft mass. A practical near-term emphasis for the Surveyor-Lander missions is in studies of Martian geology and geochemistry. Now in the early stages of development, the new lander designs will be three to ten times less massive but significantly more capable than the Pathfinder vehicle through the application of forefront technologies in structures, materials, packaging, microelectronics, autonomous operations, and miniaturization. These spacecraft will deliver to the Martian surface a new generation of miniaturized science instruments for a wide range of surface and subsurface investigations.

The Pluto Fast Flyby Mission, a voyage of discovery to the only remaining unexplored planet, will meet severe cost constraints by limiting its scientific objectives and incorporating new technologies. The mission is critical if the United States is to retain its capability for conducting long-lived deep space exploration—we are the only nation on Earth to demonstrate this extraordinary technological skill. Pluto-Charon scientific goals include intercomparing the cryogenic Titan-Triton-Pluto triad, which rivals the Venus-Earth-Mars triad in complexity; studying Pluto's unique atmosphere, which builds up and decays—comet-like—during each orbit about the Sun; studying the chemistry of the outer solar nebula; and studying the formation of the unique Pluto-Charon binary. The current baseline



The Mars Surveyor program addresses top priority exploration objectives for Mars, including: life on Mars, past or present; climate history and implications for understanding Earth's climate; sample return; and direct public involvement in exploring the unknown. The plan entails two launches to Mars every 26 months from 1996 to 2005; a fixed annual budget and mission cost caps; short development time and advantageous use of the Mars Pathfinder experience (landing system and rover operations on Mars). (NASA/JPL)

An artist's conception of the Pluto-Charon binary-planet system showing the Pluto Fast Flyby spacecraft (Pat Rawlings, SAIC, Inc.); property of NASA. Pluto lies in the background, beyond Charon.

calls for two identical spacecraft to be launched around 2001 on direct trajectories to Pluto. A flight system mass of 119 kg (current estimate, including propellant and contingency) implies a trip time of about 8 years. The spacecraft is a highly miniaturized design with no deployable structures. Advanced technology infusion has enabled weight, power, and cost reductions in every subsystem through the use of new materials and designs, microelectronics, micro-mechanical devices, low-mass packaging, resource-sharing, on-board automation and data management, low-activity cruise, minimum engineering data return, and subsystem integration. The science capabilities of this spacecraft, which include high-resolution imaging, surface composition measurements, and atmospheric characterization, will far exceed those of Voyager 2 at Triton at a small fraction of the cost.

4.2.4 Origin and Distribution of Life in the Universe

The only past space science mission specifically designed to address questions of the origin and distribution of life was the Viking mission to Mars. Nonetheless, many missions make major contributions to addressing questions encompassed by this theme. Among the future missions that will make such contributions are SIRTF, SOFIA, Mars Surveyor, and Discovery missions.

SIRTF and SOFIA address the history of the biogenic elements (carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur) from their birth in stars to their incorporation into planetary bodies. The six stages in this history are 1) nucleosynthesis and ejection into the interstellar medium; 2) chemical evolution in the interstellar medium; 3) protostellar collapse; 4) chemical evolution in the solar nebula; 5) growth of planetesimals from dust; and 6) accumulation and thermal processing of planetoids. Each of these stages involves characteristic infrared emissions, which SIRTF and SOFIA are designed to detect.

The Mars Surveyor series and Discovery missions to primitive bodies will address questions of prebiotic evolution. The strategy is to investigate the planetary and molecular processes that set the physical and chemical conditions within which living systems might have arisen. Four major objectives are to: 1) determine constraints on prebiotic evolution imposed by the physical and chemical histories of planets; 2) develop models of active boundary regions in which chemical evolution could have occurred; 3) determine what chemical systems could have served as precursors of metabolic and replicating systems both on Earth and elsewhere; and 4) determine in what forms prebiotic organic matter has been preserved in planetary materials. In addition, Mars Surveyor will shed light on the crucial link between planetary evolution and the origin of life itself.

4.3 Priority Guidelines

The following priority guidelines will preserve flexibility for responding to new opportunities or constraints, while at the same time providing for continuing progress toward achieving space science goals.

Current Program

Attention must be given to achieving the most cost-effective return on the very substantial investment in operating missions and in approved missions already under development. The scientific objectives of the major missions under development, Global Geospace Science (GGS), Cassini, and AXAF, remain of the highest priority. Substantial restructuring and descoping have occurred to achieve the highest possible science return with significantly reduced cost. Operations for missions already in orbit or under development have been scrutinized to increase efficiency, and some missions have been or will soon be terminated. The ongoing program will be reviewed periodically to ensure that all missions are carried out in the most cost-effective manner and that resources are allocated according to scientific priority.

Special consideration will be given to the Mars Surveyor Program, which is included in the President's budget for FY1995. This program provides for a responsible, yet affordable, recovery of Mars Observer science and will be considered part of the Current Program.

Future Program

To avoid stagnation, the space science plan must allow for initiation of the highest priority missions and must also lay the groundwork for investigations in the more distant future. The following elements of the program are essential:

- Provide opportunities for continued exploration and discovery. More frequent flight opportunities with shorter development times are essential to provide steady progress. The highest priority initiatives in this area are to continue the Discovery program, initiate Solar Terrestrial Probes, and begin SOFIA.
- Provide for advances at the frontiers of space science. Many fundamental questions can only be answered by more capable missions. The laws of nature dictate that the ability to detect faint signals from the distant universe or to visit the innermost and outermost regions of the solar system requires more capable spacecraft than those used in our smallest flight programs. The highest priority initiatives in this category are SIRTF, Pluto Fast Flyby, and Solar Probe.
- Leverage the U.S. investment in space science through international cooperation. NASA will take advantage of opportunities for international and interagency collaboration and cooperation to improve the scientific return of both NASA-led missions and missions led by other agencies or other countries. NASA has a successful history of cooperation with the European Space Agency, European national agencies, Canada, Japan, Russia and other nations. These kinds of efforts will be encouraged where they can effectively accomplish mutual goals through a pooling of resources and a combining of complementary strengths.
- Prepare for the future. Appropriate investments in technology development, research programs, and mission concept studies must be made. These investments provide the engine for generating new approaches to answering the fundamental questions, formulating new questions based on recent discoveries, providing new technologies with potential impact beyond NASA, and enabling future increases in the productivity of the space science program.

These priority guidelines are the result of a very difficult process in which numerous programs and missions of nearly comparable scientific merit were eliminated from active consideration, significantly reduced in scope, or postponed. When compared with the draft 1992 Strategic Plan for the Office of Space Science and Applications (OSSA), the present plan eliminates all "flagship" missions and moderate missions, in some cases deleting them entirely and in others replacing them with much smaller, more focused, and less costly moderate or small missions. Examples of flagship or moderate missions that have been deleted include: Orbiting Solar Laboratory, Astromag, Grand Tour Cluster, and Submillimeter Intermediate Mission. Missions from the draft 1992 OSSA Plan that have been included here in severely descoped form include TIMED, HESP, IMI, SIRTF, MESUR Network, and Pluto Flyby. Other missions, such as SOFIA, have been restructured and are being planned with substantial international participation. In addition, painful choices have been made between new initiatives and further operations of existing missions that continue to return very valuable data.

5. Conclusion and Summary

Throughout its history, the United States space science program has been enormously productive. Its accomplishments have rewritten the textbooks. But now, the economic environment has changed dramatically. The nation's scientific and technological goals are being reexamined and redefined. And the "social contract" between the scientific community and the Federal government is being rewritten. There is an expectation that the American public should receive more direct benefits from its investment in science and technology.

This Strategic Plan attempts to deal simultaneously with both the old and the new imperatives. It presents a carefully selected set of new scientific initiatives that build on past accomplishments to continue NASA's excellence in space science. At the same time, it responds to fiscal constraints by defining a new approach to planning, developing, and operating space science missions. In particular, investments in new technologies will permit major scientific advances to be made with smaller, more focused, and less costly missions. With the introduction of advanced technologies, smaller does not have to mean less capable. The focus on new technologies also provides an opportunity for the space science program to enhance its direct contributions to the country's economic base. At the same time, the program can build on public interest to strengthen its contributions to education and scientific literacy.

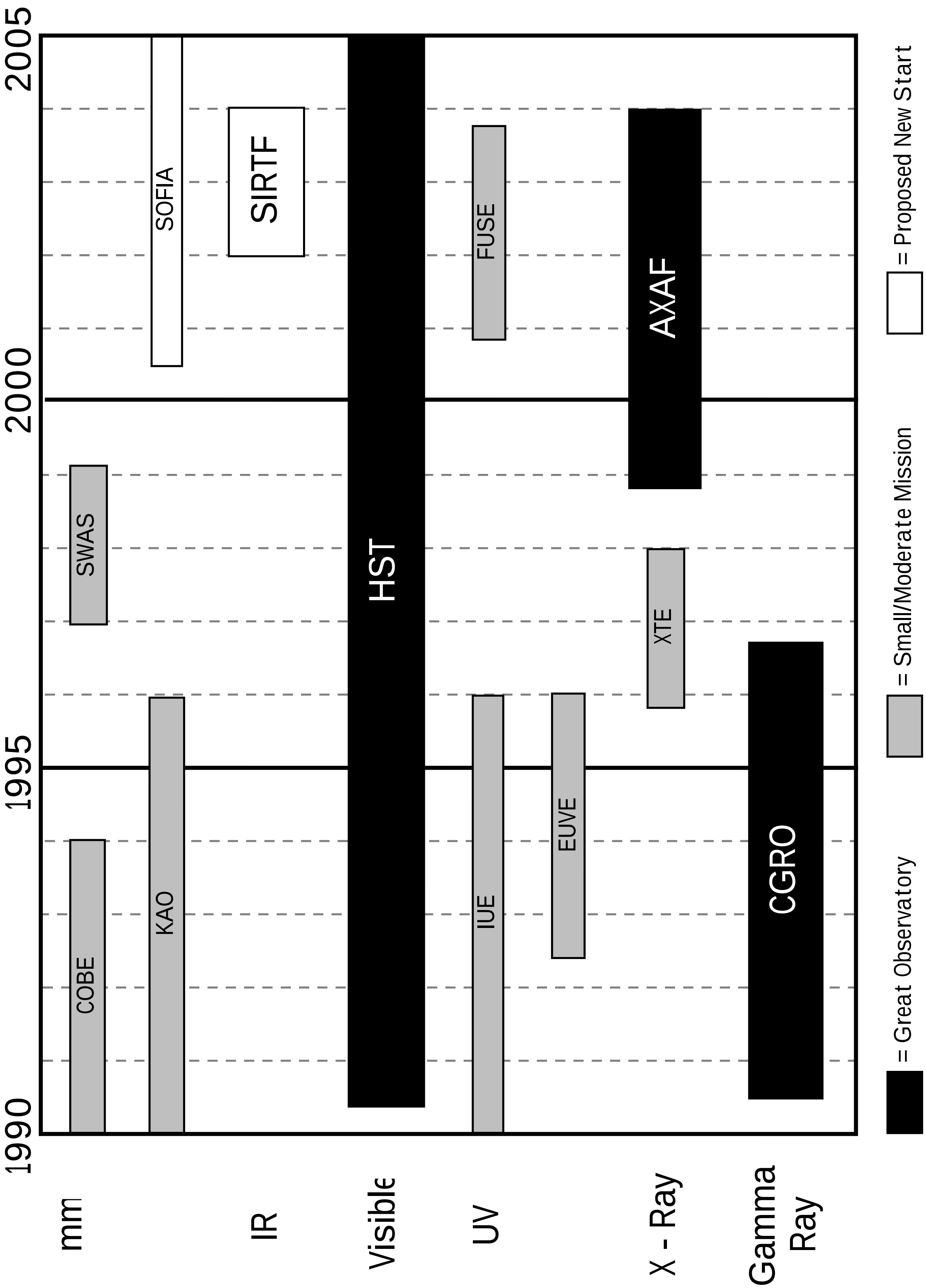
With this Plan, we are taking the first steps toward shaping the space science program of the Twenty-First Century. In doing so, we face major challenges. It will be a very different program than might have been envisioned even a few years ago. But it will be a program that remains at the forefront of science, technology, and education. We intend to continue rewriting the textbooks.

Appendices

Appendix A: Acronyms

ACE - Advanced Composition Explorer
AXAF - Advanced X-Ray Astrophysics Facility
AMPTE - Active Magnetosphere Particle Tracer Experiment
CGRO - Compton Gamma Ray Observatory
COBE - Cosmic Background Explorer
EUVE - Extreme Ultraviolet Explorer
FAST - Fast Auroral Snapshot Explorer
FUSE - Far Ultraviolet Spectroscopy Explorer
GGS - Global Geospace Science
GP-B - Gravity Probe-B
GTC - Grand Tour Cluster
HESI - High Energy Solar Imager
HESP - High Energy Solar Physics
HST - Hubble Space Telescope
IMI - Inner Magnetosphere Imager
IMP - Interplanetary Monitor Probe
IRAS - Infrared Astronomy Satellite
ISEE - International Sun Earth Explorer
ISM - Interstellar Medium
IUE - International Ultraviolet Explorer
KAO - Kuiper Airborne Observatory
MESUR Network - Mars Environmental Survey Network
MI -Magnetospheric Imager
MO&DA - Mission Operations and Data Analysis
NEAR - Near Earth Asteroid Rendezvous
OGO - Orbiting Geophysical Observatory
OSO - Orbiting Solar Observatory
OSS - Office of Space Science
OSSA - Office of Space Science and Applications
SAMPEX - Solar, Anomalous, and Magnetospheric Particle Explorer
SIRTF - Space Infrared Telescope Facility
SMM - Solar Maximum Mission
SOFIA - Stratospheric Observatory for Infrared Astronomy
SOHO - Solar and Heliospheric Observatory
SWAS - Submillimeter Wave Astronomy Satellite
TIMED - Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics
XTE - X-ray Timing Explorer

Appendix B: Illustration of the Galaxy and the Universe Mission Strategy by Spectral Wavelength



The fundamental strategy for understanding the Galaxy and the Universe is to enable basic discoveries by providing observational capabilities at all wavelengths. Many windows are being successfully opened on the Universe by projects which are on-going or in development (the Great Observatories and small/moderate missions illustrated). The final capability to be completed is infrared astrophysics—the SIRTF and SOFIA missions. Providing these observatories in the timeframe shown will open the discovery window for objects too cool, too dusty, or too highly redshifted to be conspicuous with other missions. Having SIRTF, HST, and AXAF observing contemporaneously will allow comprehensive follow-up and understanding of phenomena at any wavelength.

Appendix C: Illustration of Planetary System Origin and Evolution Mission Strategy by Planetary Object

	Inner Planets				Small Bodies		Outer Planets					Extrasolar Planetary Systems
	Mercury	Venus	Moon	Mars	Asteroids	Comets	Jupiter	Saturn	Uranus	Neptune	Pluto	Extrasolar
Reconnaissance	Mariner 10 Flyby	Mariner 2 Flyby Mariner 5 Flyby Mariner 10 Flyby	Ranger 7 Photo Ranger 8 Photo Ranger 9 Photo	Mariner 4 Flyby Mariner 6 Flyby Mariner 7 Flyby	Galileo Flybys Cassini Flybys	International Cometary Explorer	Pioneer 10 Flyby Pioneer 11 Flyby Voyager 1 Flyby Voyager 2 Flyby	Pioneer 11 Flyby Voyager 1 Flyby Voyager 2 Flyby	Voyager 2 Flyby	Voyager 2 Flyby	Pluto Flyby	Phase 0: Keck II
Exploration	*Mercury Flyby/Orbiter*	Pioneer Venus Orbiter & Probes Magellan Radar Mapper	Lunar Orbiter 1-5 Surveyor 1, 3, 5-7 Landers Apollo 11-17 Clementine Orbiter	Mariner 9 Orbiter Viking 1, 2 Orbiters & Landers	Near-Earth Asteroid Rendezvous	*ESA Rosetta Comet Orbiter/Lander*	Galileo Orbiter & Jupiter Probe	Cassini Orbiter & Titan Probe				*Phase 1: Orbital System*
Intensive Study		*Venus Atmosphere & Surface Probes*	*International Orbiters, Penetrators, Landers*	Mars Pathfinder Mars Surveyors *Int'l Mars Network* *Int'l Mars Rover & Sample Return*	*Asteroid Multiple Flybys, Rendezvous, Sample Return*	*Comet Multiple Flybys, Rendezvous, Sample Return*						*Phase 2: Lunar-based System*

Discovery

Past Mission | Current Mission | Next Step, This Plan | *Future Next Step*

The mission strategy for Planetary System Origin and Evolution encompasses all known objects in the Sun's planetary system, except for the Earth, the Sun, and the interplanetary medium. It also includes studies of the origin and evolution of planetary systems and an observational program to search for and characterize extrasolar planets. The intellectual framework begins with reconnaissance missions, which are the first phase of inquiry and are characterized by discovery and a basic assessment of the target body, its environment, and its place in the larger context of our planetary system. These missions have focused typically on photo- and spectrometer-reconnaissance and the determination of basic properties such as the body's gravitational field. The exploration phase implies a return mission for orbital and/or landed science investigations. Exploration of a comet or asteroid could be a first visit to that object, while earlier reconnaissance missions have occurred for that broad class of objects. The last phase of the program consists of missions for intensive study, which focus on answering fundamental questions such as the body's origin and evolution, and could include highly detailed investigations of its current nature and the relationship of its characteristics to the origin and evolution of Earth and of life on Earth. These missions imply in-depth studies and will often require the use of our most powerful and innovative technologies—commensurate with the importance of the investigation and the associated technical challenges.

Appendix D: Illustration of Sun-Earth-Heliosphere Connection Mission Strategy

	SUN - EARTH CONNECTIONS			SUN - HELIOSPHERE CONNECTIONS		
	Solar Activity & Atmospheres	Terrestrial Magnetosphere	Iono-Thermo-Mesosphere Physics	Inner Heliosphere	Interplanetary Space	Outer Heliosphere
DISCOVERY (Pioneering efforts)	OSO 1-7 Skylab ATM	Explorers IMP 1-7 OGO's >>SAMPEX<<	Atmospheric Explorers	Skylab ATM SMM	Mariners ISEE's Pioneers 10,11 IMP 1-7 Voyagers 1, 2 >>Ulysses<<	>>Pioneers 10,11<< >>Voyagers 1,2<<
EXPLORATION (Reconnaissance)	SMM >>Yohkoh<<	ISEE 1-3 AMPTE CRRES	Dynamics Explorers *Tether* TIMED*	*SOHO* Solar Probe Mercury Orbiter	>>IMP-8<<	(Pluto Fast Flyby) Interstellar Probe
INTENSIVE STUDY (Achieving physical analysis)	*SOHO* HESI* Orbiting Solar Lab.	>>Geotail<< *Wind & Polar* *FAST* *Cluster* MI* Grand Tour Cluster			>>SAMPEX<< *Wind* *ACE*	

* Solar Terrestrial Probes program proposed in this plan.

KEY:
- Past Missions
- >>Current Missions<< (operational)
- *Current Missions (in development)*
- NEXT PROGRAM (this plan)
- Future (next step)

The mission strategy for the Sun-Earth-Heliosphere Connection has two principal elements:

- Sun-Earth Connections Program concerns all aspects of the Sun (its internal structure, visible atmospheres, and activity), the planetary magnetospheres (especially of the Earth), and the Earth's upper atmospheres (ionosphere, thermosphere and mesosphere) that are directly affected by solar activity; and
- Sun-Heliosphere Connections Program studies the interplanetary medium from its origin as the solar wind in the Sun's corona (the inner heliosphere), through interplanetary space, and finally to its termination in the outer heliosphere where it confronts the interstellar medium.

All of these subjects share common physical linkage through the Sun's variable energy outputs in the form of a magnetized plasma (the solar wind), energetic particles and photons (especially in the energetic ultraviolet and x-ray wavelengths). The techniques used to study these subjects are as highly diversified as the phenomena themselves, ranging from optical telescopes to small detectors that measure the solar wind *in situ*. In all cases, the progression of missions has been from that of discovery, through successive stages of exploration, and finally into the realm of intensive study with the ultimate goal of achieving predictive capability. The principal components of this current plan are the Solar Terrestrial Probes (shown in bold type with shaded background), which are three small missions that make coordinated, next-step advances across the entire breadth of the Sun-Earth-Connections Program; and the Solar Probe mission that for the first time will send instruments into close proximity of the Sun to directly measure the origins of the solar wind.

Appendix E: National Academy of Science Strategies for Space Science

Space Studies Board

The following list presents the major Space Science reports of the Space Studies Board (SSB) and its committees from 1964 to present. The Board's reports have been published by the National Academy Press since 1981. Prior to that date publication was by the National Academy of Sciences.

1993

Improving NASA's Technology for Space Science, Committee on Space Science Technology Planning, a joint committee of the SSB and the Aeronautics and Space Engineering Board

Scientific Prerequisites for the Human Exploration of Space, SSB Committee on Human Exploration

1992

Biological Contamination of Mars: Issues and Recommendations, SSB Task Group on Planetary Protection

Setting Priorities for Space Research: Opportunities and Imperatives, SSB Task Group on Priorities in Space Research - Phase I

1991

Assessment of Programs in Solar and Space Physics - 1991, SSB Committee on Solar and Space Physics and Board on Atmospheric Sciences and Climate Committee on Solar-Terrestrial Research

Assessment of Satellite Earth Observation Programs - 1991, SSB Committee on Earth Studies

Assessment of Solar System Exploration Programs - 1991, SSB Committee on Planetary and Lunar Exploration

1990

International Cooperation for Mars Exploration and Sample Return, Committee on Cooperative Mars Exploration and Sample Return

The Search for Life's Origins: Progress and Future Directions in Planetary Biology and Chemical Evolution, SSB Committee on Planetary Biology and Chemical Evolution

Strategy for the Detection and Study of Other Planetary Systems and Extrasolar Planetary Materials: 1990-2000, SSB Committee on Planetary and Lunar Exploration

Update to Strategy for Exploration of the Inner Planets, SSB Committee on Planetary and Lunar Exploration

1988

Selected Issues in Space Science Data Management and Computation, SSB Committee on Data Management and Computation

Space Science in the Twenty-First Century - Astronomy and Astrophysics, SSB Task Group on Astronomy and Astrophysics

Space Science in the Twenty-First Century - Fundamental Physics and Chemistry, SSB Task Group on Fundamental Physics and Chemistry

Space Science in the Twenty-First Century - Overview, SSB Steering Group on Space Science in the Twenty-First Century

Space Science in the Twenty-First Century - Planetary and Lunar Exploration, SSB Task Group on Planetary and Lunar Exploration

Space Science in the Twenty-First Century - Solar and Space Physics, SSB Task Group on Solar and Space Physics

1987

Long-Lived Space Observatories for Astronomy and Astrophysics, SSB Committee on Space Astronomy and Astrophysics

1986

The Explorer Program for Astronomy and Astrophysics, SSB Committee on Space Astronomy and Astrophysics

Issues and Recommendations Associated with Distributed Computation and Data Management Systems for the Space Sciences, SSB Committee on Data Management and Computation

Remote Sensing of the Biosphere, SSB Committee on Planetary Biology and Chemical Evolution

A Strategy for Exploration of the Outer Planets: 1986-1996, SSB Committee on Planetary and Lunar Exploration

United States and Western Europe Cooperation in Planetary Exploration, Joint Working Group on Cooperation in Planetary Exploration of the SSB/NRC and the Space Science Committee of the European Science Foundation

1985

An Implementation Plan for Priorities in Solar-System Space Physics, SSB Committee on Solar and Space Physics

An Implementation Plan for Priorities in Solar-System Space Physics - Executive Summary, SSB Committee on Solar and Space Physics

Institutional Arrangements for the Space Telescope - A Mid-Term Review, Space Telescope Science Institute Task Group/SSB Committee on Space Astronomy and Astrophysics

The Physics of the Sun, Panels of the Space Science Board

1984

Solar-Terrestrial Data Access, Distribution, and Archiving, Joint Data Panel of the Committee on Solar-Terrestrial Research

A Strategy for the Explorer Program for Solar and Space Physics, SSB Committee on Solar and Space Physics

1983

An International Discussion on Research in Solar and Space Physics, SSB Committee on Solar and Space Physics

The Role of Theory in Space Science, SSB Theory Study Panel

1982

Data Management and Computation - Volume I: Issues and Recommendations, SSB Committee on Data Management and Computation

1981

Origin and Evolution of Life: Implications for the Planets: A Scientific Strategy for the 1980s, SSB Committee on Planetary Biology and Chemical Evolution

Strategy for Space Research in Gravitational Physics in the 1980s, SSB Committee on Gravitational Physics

1980

Solar-System Space Physics in the 1980s: A Research Strategy, SSB Committee on Solar and Space Physics

Strategy for the Exploration of Primitive Solar-System Bodies - Asteroids, Comets, and Meteoroids: 1980-1990, SSB Committee on Planetary and Lunar Exploration

1979

The Science of Planetary Exploration, Eugene H. Levy and Sean C. Solomon, members of SSB Committee on Planetary and Lunar Exploration

Space Plasma Physics - The Study of Solar-System Plasmas, Volume 2, Working Papers, Part 1, Solar-System Magnetohydrodynamics, SSB Study Committee and Advocacy Panels

Space Plasma Physics - The Study of Solar-System Plasmas, Volume 2, Working Papers, Part 2, Solar-System Plasma Processes, SSB Study Committee and Advocacy Panels

A Strategy for Space Astronomy and Astrophysics for the 1980s, SSB Committee on Space Astronomy and Astrophysics

Other Relevant National Research Council Reports

1991

The Decade of Discovery in Astronomy and Astrophysics, (the "Bahcall Report"), National Academy Press, Washington, DC.

1986

Physics Through the 1990s, National Academy Press, Washington, DC.

1982

Astronomy and Astrophysics for the 1980s. Volume I: Report of the Astronomy Survey Committee, (the "Field Report"). National Academy Press, Washington, DC.

1972

Astronomy and Astrophysics for the 1970s. (the "Greenstein Report"), National Academy of Sciences, Washington, DC.

1964

Ground-based Astronomy : A Ten-Year Program (the "Whitford Report"). National Academy of Sciences, Washington, DC.