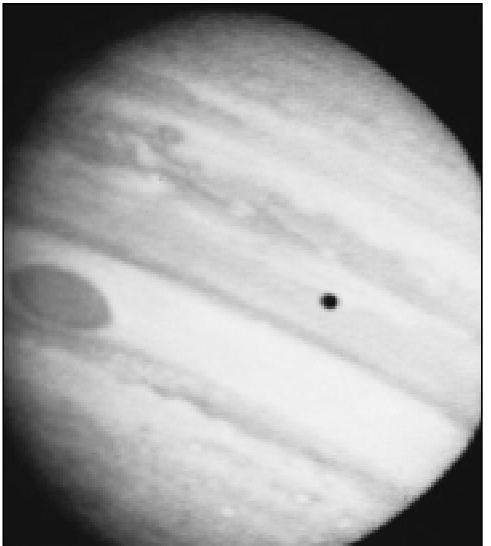

CHAPTER FOUR

SPACE SCIENCE

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SPACE SCIENCE

Introduction

NASA's Space Science and Applications program was responsible for planning, directing, executing, and evaluating NASA projects focused on using the unique characteristics of the space environment for scientific study of the universe, solving practical problems on Earth, and providing the scientific research foundation for expanding human presence into the solar system. The space science part of these responsibilities (the subject of this chapter) aimed to increase scientific understanding through observing the distant universe, exploring the near universe, and understanding Earth's space environment.

The Office of Space Science (OSS) and the Office of Space Science and Applications (OSSA) formed the interface among the scientific community, the president, and Congress. These offices evaluated ideas for new science of sources and pursued those thought most appropriate for conceptual study.[1] They represented the aspirations of the scientific community, proposed and defended programs before the Office of Management and Budget and Congress, and conducted the programs that Congress authorized and funded. NASA's science missions went through definable phases. In the early stages of a scientific mission, the project scientist, study scientist, or principal investigator would take the lead in specifying the science that the proposed mission intended to achieve and determined its feasibility. Once the mission was approved and preparations were under way, the mission element requirements, such as schedule and cost, took priority. However, once the mission was launched and the data began to be transmitted, received, and analyzed, science again became dominant. From 1979 to 1988, NASA had science missions that

[1]The ideas for new science came from a variety of sources, among them the various divisions within the science offices, the NASA field installations, the National Academy of Sciences, industry and academia, other U.S. government agencies, international organizations, NASA advisory committees, and the demand caused by shifting national priorities.

were in each of these stages—some in the early conceptual and mission analysis stages, others in the definition, development, and execution stages, and still others in the operational stage, with the data being used by the scientific community.

Thus, although NASA launched only seventeen dedicated space science missions and conducted four science missions aboard the Space Shuttle from 1979 to 1988, compared to the previous decade when the agency flew approximately sixty-five space science missions, the agency also continued to receive and analyze impressive data from earlier launches and prepared for future missions, some delayed following the *Challenger* accident. In addition to the delays caused by the *Challenger* accident, level funding also contributed to the smaller number of missions. NASA chose to invest its resources in more complex and costly missions that investigated a range of phenomena rather than fly a series of missions that investigated similar phenomena.

In addition to those managed by NASA, some NASA-launched missions were for other U.S. government or commercial organizations and some were in partnerships with space agencies or commercial entities from other countries. The following sections identify those scientific missions in which NASA provided only launch-related services or other limited services.

In spite of the small number of missions, NASA's OSS and OSSA were very visible. Almost every Space Shuttle mission had space science experiments aboard in addition to the dedicated Spacelab missions. Furthermore, scientists received spectacular and unprecedented data from the missions that had been launched in the previous decade, particularly the planetary probes.

This chapter describes each space science mission launched during these years as well as those conducted aboard the Space Shuttle. An overview of findings from missions launched during the previous decade is also presented.

The Last Decade Reviewed (1969–1978)

From 1969 to 1978, NASA managed space science missions in the broad areas of physics and astronomy, bioscience, and lunar and planetary science. The majority of NASA's science programs were in the physics and astronomy area, with fifty-three payloads launched. Explorer and Explorer-class satellites comprised forty-two of these investigative missions, which provided scientists with data on gamma rays, x-rays, energetic particles, the solar wind, meteoroids, radio signals from celestial sources, solar ultraviolet radiation, and other phenomena. Many of these missions were conducted jointly with other countries.

NASA launched four observatory-class physics and astronomy spacecraft programs between 1969 and 1978. These provided flexible orbiting platforms for scientific experiments. Participants in the Orbiting Geophysical Observatories gathered information on atmospheric composition. The Orbiting Astronomical Observatory returned volumes of data on the composition, density, and physical state of matter in interstellar space to scientists on Earth. It was the most complex automated spacecraft yet in the space science program. It took the first ultraviolet photographs of the stars and produced the first hard evidence of the existence of black holes in space. The High Energy Astronomy Observatories (HEAO) provided high-quality data on x-ray, gamma ray, and cosmic ray sources. HEAO-1 was the heaviest scientific satellite to date. The Orbiting Solar Observatory missions took measurements of the Sun and were the first satellites to capture on film the beginning of a solar flare and the consequent streamers of hot gases that extended out 10.6 million kilometers. It also discovered "polar ice caps" on the Sun (dark areas thought to be several million degrees cooler than the normal surface temperatures).

NASA launched several other Explorer-class satellites in cooperative projects with other countries or other government agencies. Uhuru, launched from the San Marco launch platform in 1970, scanned 95 percent of the celestial sphere for sources of x-rays and discovered three new pulsars. The bioscience program sponsored only Biosatellite 3, whose objective was to determine the effects of weightlessness on a monkey. In addition, NASA's life scientists designed many of the experiments that were conducted on Skylab.

NASA's Office of Planetary Programs explored the near planets with the Pioneer and Mariner probes. NASA conducted three Mariner projects during the 1970s, which investigated Mars, Mercury, and Venus. Mariner 9 became the first American spacecraft to go into orbit around another planet; it mapped 95 percent of the Martian surface. The two Viking landers became the first spacecraft to soft-land on another planet when they landed on Mars and conducted extended mission operations there while two orbiters circled the planet and mapped the surface.

With the Pioneer program, NASA extended its search for information to the outer planets of the solar system. Pioneer 10 (traveling at the highest velocity ever achieved by a spacecraft) and Pioneer 11 left Earth in the early 1970s, reaching Jupiter in 1973 and Saturn in 1979. Eventually, in 1987, Pioneer 10 would cross the orbit of Pluto and become the first manufactured object to travel outside our solar system. NASA also sent two Voyager spacecraft to the far planets. These excursions produced impressive high-resolution images of Jupiter and Saturn.

Detailed information relating to space science missions from 1969 through 1978 can be found in Chapter 3 of the *NASA Historical Data Book, Volume III*.[2]

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[2]Linda Neuman Ezell, *NASA Historical Data Book, Volume III: Programs and Projects, 1969–1978* (Washington, DC: NASA SP-4012, 1988).

Space Science (1979–1988)

During the ten-year period from 1979 to 1988, NASA launched seventeen space science missions. These included missions sponsored by OSS or OSSA (after its establishment in 1981), missions launched for other U.S. government agencies, and missions that were part of an international effort. The science missions were primarily in the disciplines of Earth and planetary exploration, astrophysics, and solar terrestrial studies. The Life Sciences Division, while not launching any dedicated missions, participated heavily in the Spacelab missions and other scientific investigations that took place during the decade.

The decade began with the "year of the planets" in space exploration. During 1979, scientists received their first high-resolution pictures of Jupiter and five of its satellites from Voyagers 1 and 2. Pioneer 11 transmitted the first close-up pictures of Saturn and its moon Titan. Both of these encounters revealed previously unknown information about the planets and their moons. Pioneer Venus went into orbit around Venus in December 1978, and it returned new data about that planet throughout 1979. Also, one Viking orbiter on Mars continued to transmit pictures back to Earth, as did one lander on the planet's surface.

Spectacular planetary revelations continued in 1980 with Voyager 1's flyby of Saturn. Dr. Bradford Smith of the University of Arizona, the leader of the Voyager imaging team, stated that investigators "learned more about Saturn in one week than in the entire span of human history."[3] Thousands of high-resolution images revealed that the planet had hundreds, and perhaps thousands, of rings, not the six or so previously observed. The images also showed three previously unknown satellites circling the planet and confirmed the existence of several others.

Scientists also continued receiving excellent data from NASA's two Earth-orbiting HEAOs (launched in 1977 and 1978, respectively). HEAO-2 (also referred to as the Einstein Observatory) returned the first high-resolution images of x-ray sources and detected x-ray sources 1,000 times fainter than any previously observed and 10 million times fainter than the first x-ray stars observed. Scientists studying HEAO data also confirmed the emission of x-rays from Jupiter—the only planet other than Earth known to produce x-rays. Mission operations ceased in 1981, but more than 100 scientific papers per year were still being published using HEAO data in the mid-1990s.

The Solar Maximum Mission, launched in 1980, gathered significant new data on solar flares and detected changes in the Sun's energy output. Scientists stated that a cause-and-effect relationship may exist between sustained changes in the Sun's energy output and changes in Earth's weather and climate. The satellite's observations were part of NASA's

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[3]"Highlights of 1980 Activities," *NASA News,* Release 80-199, December 24, 1980.

solar monitoring program, which focused on studying the Sun during a nineteen-month period when sunspot activity was at a peak of its eleven-year cycle of activity.

During 1981, OSS merged with the Office of Space and Terrestrial Applications to form OSSA. OSSA participated in the Space Shuttle program with its inclusion of the OSTA-1 payload aboard STS-2. This was the first scientific payload to fly on the STS.

Exploration of the solar system continued with Voyager 2's successful encounter with Saturn in August 1981. Building on the knowledge gained by the Voyager 1 encounter, Voyager 2 provided information relating to the ring structure in detail comparable to a street map and enabled scientists to revise their theories of the ring structure. After leaving Saturn's surroundings, Voyager 2 embarked on a trajectory that would bring it to Uranus in 1986.

Pioneer 6 continued to return interplanetary and solar science information while on the lengthiest interplanetary mission to date. Pioneer 10 reached more than 25 thousand million miles from the Sun. Pioneer missions to Venus and Mars also continued transmitting illuminating information about these planets.

Beginning in 1982, an increasing number of space science experiments were flown aboard the Space Shuttle. The Shuttle enabled scientists to conduct a wide variety of experiments without the commitment required of a dedicated mission.[4] Instruments on satellites deployed from the Shuttle also investigated the Sun's ultraviolet energy output, measured the nature of the solar wind, and detected frozen methane on Pluto and Neptune's moon Triton. In addition, the Pioneer and the Viking spacecraft continued to record and transmit data about the planets each was examining.

The Infrared Astronomical Satellite, a 1983 joint venture among NASA, the Netherlands, and the United Kingdom, revealed a number of intriguing discoveries in its ten-month-long life. These included the possibility of a second solar system forming around the star Vega, five undiscovered comets, a possible tenth planet in our solar system, and a solar dust cloud surrounding our solar system.

During 1983, the Space Telescope, then scheduled for launch in 1986, was renamed the Edwin P. Hubble Space Telescope. Hubble was a member of the Carnegie Institute, whose studies of galaxies and discoveries of the expanding universe and Hubble's Constant made him one of America's foremost astronomers.

In 1984, the Smithsonian Institution's National Air and Space Museum became the new owner of the Viking 1 lander, which was parked

[4]Tables in Chapter 3 describe many of the experiments conducted aboard the Space Shuttle. Spacelab experiments and OSS and Spacelab missions are described in this chapter. The Office of Space and Terrestrial Applications missions are addressed in Chapter 2, "Space Applications," and OAST-1 is described in Chapter 3, "Aeronautics and Space Research and Technology," both in Volume VI of the *NASA Historical Data Book.*

on the surface of Mars. The transfer marked the first time an object on another planet was owned by a United States museum. Also in 1984, the Hubble Space Telescope's five scientific instruments underwent acceptance testing at the Goddard Space Flight Center in preparation for an anticipated 1986 launch. The acceptance testing represented the completion of the most critical element of the final checkout steps for the instruments before their assembly aboard the observatory. NASA announced the start of the Extreme Ultraviolet Explorer, a new satellite planned for launch from the Space Shuttle in 1988 that eventually was launched in 1992 by a Delta launch vehicle. The mission would make the first all-sky survey in the extreme ultraviolet band of the electromagnetic spectrum.

An encounter with the Comet Giacobini-Zinner by the International Cometary Explorer highlighted NASA's 1985 science achievements. This was the first spacecraft to carry out the on-site investigation of a comet. Also during 1985, Spacelab 3 carried a series of microgravity experiments aboard the Shuttle, and astronauts on Spacelab 2 conducted a series of astronomy and astrophysics experiments. An instrument pointing system on Spacelab 2, developed by the European Space Agency, operated for the first time and provided a stable platform for highly sensitive astronomical instruments.

The *Challenger* accident in January 1986 temporarily halted science that relied on the Shuttle for deploying scientific satellites and for providing a setting for on-board experiments. Four major scientific missions planned for 1986 were postponed, including Astro-1, the Hubble Space Telescope, and two planetary missions—Galileo and Ulysses. The Spartan Halley spacecraft, to be deployed from *Challenger,* was destroyed. However, other science activities still took place. Also, the Space and Earth Science Advisory Committee of the NASA Advisory Council issued a report on the status of space science within NASA. The two-year study, titled "The Crisis in Space and Earth Science, A Time for New Commitment," called for greater attention and higher priority for science programs. The most notable 1986 achievement was Voyager 2's encounter with Uranus in January. This encounter provided data on a planetary body never before examined at such close range. From Uranus, the Voyager continued traveling toward a 1989 rendezvous with Neptune.

In October 1987, NASA issued a revised manifest that reflected the "mixed fleet" concept. This dictated that NASA use the Shuttle only for missions that required human participation or its special capabilities. Some science missions, which had been scheduled for the Shuttle, could be transferred to an expendable launch vehicle with no change in mission objectives. No science missions were launched in 1987.

Only one expendable launch vehicle space science launch took place in 1988, but with the resumption of Space Shuttle flights that spring, NASA prepared for the 1989 launches of several delayed space science missions. This included the Hubble Space Telescope, scheduled for launch in December 1989 (but not deployed until April 1990), which underwent comprehensive ground system tests in June 1988. The

Magellan spacecraft was delivered to the Kennedy Space Center in October 1988. This spacecraft, scheduled for launch in April 1989, would map the surface of Venus. Galileo, scheduled for launch in October 1989, underwent additional minor modifications associated with its most recent Venus-Earth-Earth gravity assist trajectory.

Management of the Space Science Program

NASA managed its space science and applications program from a single office, OSSA, from November 1963 to December 1971. A 1971 reorganization split the office into two organizations: the OSS and the Office of Space and Terrestrial Applications.

Office of Space Science

NASA managed its space science programs from a single office from December 1971 until November 9, 1981 (Figure 4–1). Noel W. Hinners led OSS until his departure from NASA in February 1979. (He returned as director of the Goddard Space Flight Center in 1982.) Thomas A. Mutch led the office from July 1979 through the fall of 1980, when Andrew Stofan became acting associate administrator.

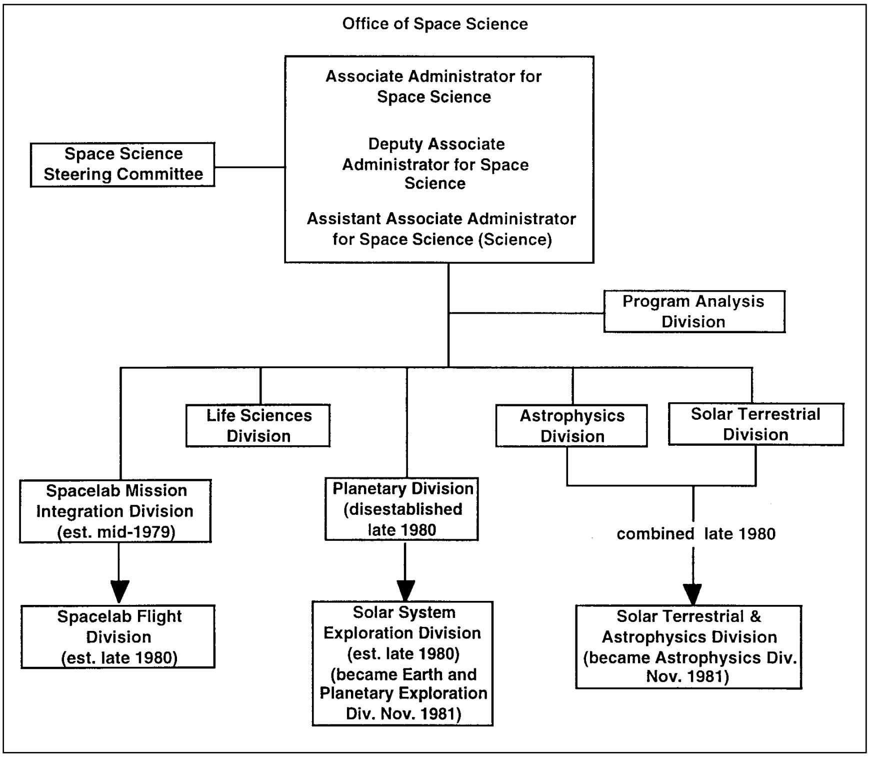

Figure 4–1. Office of Space Science (Through November 1981)

In 1979, OSS included divisions for astrophysics, life sciences, planetary science, solar terrestrial science, and program analysis. The Planetary Division was renamed the Solar System Exploration Division in late 1980. This division was disestablished at the time of the reorganization in 1981 and re-formed as the new Earth and Planetary Exploration Division, existing with this title until 1984, when it regained its former title of the Solar System Exploration Division.

The Spacelab Mission Integration Division, which was established in mid-1979, evolved into the Space Flight Division in late 1980. Also in late 1980, the Astrophysics Division and the Solar Terrestrial Division combined into the Solar Terrestrial and Astrophysics Division. This division existed until the reorganization in November 1981, when it re-formed as the Astrophysics Division.

Office of Space Science and Applications

In November 1981, NASA combined OSS and the Office of Space and Terrestrial Applications (OSTA) into the single OSSA (Figure 4–2). NASA Administrator James E. Beggs stated that the consolidation was done because of the program reductions that had occurred in the preceding years and because of the similarity of the technologies that both OSS and OSTA pursued. When the consolidation took place, OSSA consisted of divisions for communications, life sciences, astrophysics, Earth and

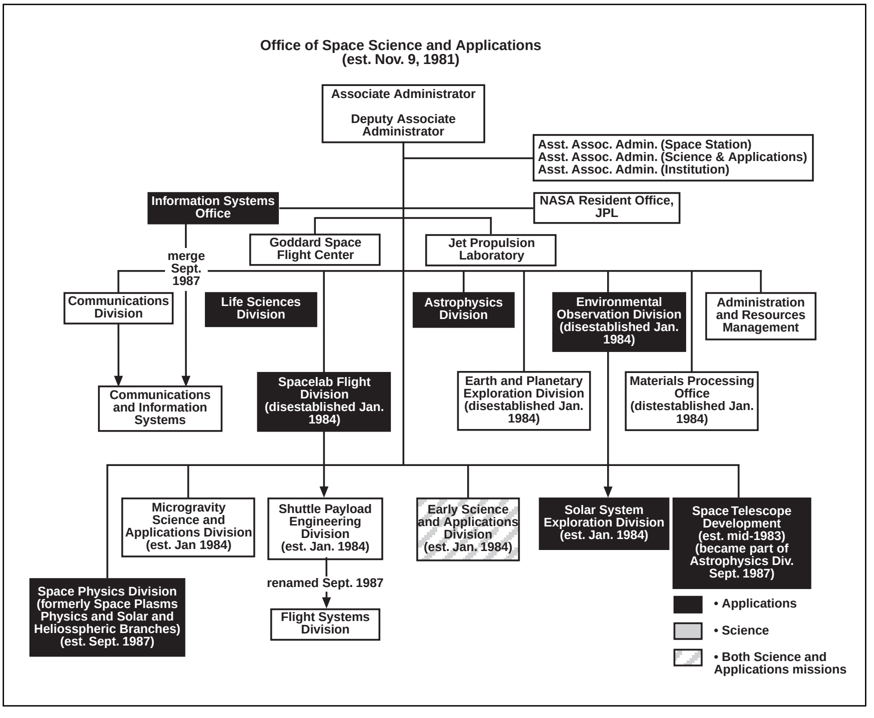

Figure 4–2. Office of Space Science and Applications (Established November 1981)

planetary exploration, Spacelab flight, environmental observation, and administration and resources management; it also had materials processing and information systems offices. The reorganization also placed the Goddard Space Flight Center and the Jet Propulsion Laboratory under the administrative management of OSSA. Andrew Stofan led OSSA as acting associate administrator until the appointment of Burton I. Edelson on February 14, 1982. Lennard A. Fisk succeeded Dr. Edelson in April 1987.

The Earth and Planetary Exploration Division, the Spacelab Flight Division, the Environmental Observation Division, and the Materials Processing Office were disestablished in January 1984. At that time, the Earth and Planetary Exploration Division became the Solar System Exploration Division, and the Spacelab Flight Division became the Shuttle Payload Engineering Division. NASA also established a new Microgravity Sciences and Applications Division and a new Earth Science and Applications Division. In September 1987, the Communications Division and the Information Systems Office merged into the Communications and Information Systems Division. NASA also promoted the Space Plasma Physics Branch and the Solar and Heliospheric Branch to the Space Physics Division. The Space Plasma Physics Branch had been part of the Earth Science and Applications Division, and the Solar and Heliospheric Branch came from the Astrophysics Division. The Space Telescope Development Division, which had been established in mid-1983, became part of the Astrophysics Division. At the same time, the Shuttle Payload Engineering Division was renamed the Flight Systems Division.

Of these divisions, life sciences, astrophysics, Earth and planetary exploration, space physics, solar system exploration, and space telescope development were considered science divisions rather than applications. This chapter covers missions that are managed by these science divisions.

The Life Sciences Division was led by Gerald Soffen through 1983, when he was succeeded by Arnauld Nicogossian. Astrophysics programs were led by Theodrick B. Norris through mid-1979, when Franklin D. Martin assumed the role of director. He remained in place when the division combined with the Solar, Terrestrial Division in 1980 (which had been headed by Harold Glaser) through early 1983. At that time, C.J. Pellerin was named to the post.

Angelo Guastaferro led the Planetary Division until it was disestablished in late 1980. Guastaferro moved to the new Solar System Exploration Division, where he remained through early 1981, when he moved to the Ames Research Center. Daniel Herman served as director of this division until the OSSA reorganization in November 1981, when the division was eliminated. When the Solar Systems Exploration Division was reestablished in 1984, Geoffrey Briggs headed it.

Jesse W. Moore led the Spacelab Mission Integration Division, which became the Spacelab Flight Division, until the November 1981 reorganization. Michael Sander assumed the leadership post at that time and held it until the division was disestablished in 1983. James C. Welch headed the Space Telescope Development Division until it was eliminated in September 1987. The Space Physics Division, which was established in September 1987, was led by Stanley Shawhan.

Office of Chief Scientist

The Office of Chief Scientist was also integral to NASA's science activities. NASA formed this office in 1977 as "a revised role for the [agency's] associate administrator."[5] Its purpose was to "promote across-the-board agency cognizance over scientific affairs and interaction with the scientific community." The chief scientist was responsible for "advising the Administrator on the technical content of the agency's total program from the viewpoint of scientific objectives" and "will serve as a focal point for integrating the agency's programs [and] plans and for the use of scientific advisory committees."[6]

John E. Naugle served as chief scientist through June 1979. The position was vacant until he returned as acting chief scientist in December 1980, remaining until mid-1981. The position was vacant again until the appointment of Frank B. McDonald in September 1982. McDonald served as chief scientist until the appointment of Noel Hinners in 1987, who held that role concurrently with his position as NASA associate deputy administrator–institution.

Office of Exploration

In June 1987, the NASA administrator established the Office of Exploration. Also related to NASA's science activities, this office was to meet the need for specific activities supporting the long-term goal to "expand human presence and activity beyond Earth orbit into the Solar System."[7] The office was responsible for coordinating NASA planning activities, particularly to the Moon and Mars. Major responsibilities were to analyze and define missions proposed to achieve the goal of human expansion of Earth, provide central coordination of technical planning studies that involved the entire agency, focus on studies of potential lunar and Martian initiatives, and identify the prerequisite investments in science and advance technology that must be initiated in the near term to achieve the initiatives. Primary concentrations of the Office of Exploration included mission concepts and scenarios, science opportunities, prerequisite technologies and research, precursor missions, infrastructure support requirements, and exploration programmatic

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[5]"NASA Reorganization," NASA Special Announcement, October 25, 1977.

[6]Additional responsibilities are listed in NASA Management Instruction 1103.36, "Roles and Responsibilities—Chief Scientist," May 17, 1984.

[7]Office of the Press Secretary, "Presidential Directive on National Space Policy," January 5, 1988.

requirements of resources and schedules. John Aaron served as acting assistant administrator until the appointment of Franklin D. Martin as assistant administrator in December 1988.

Money for Space Science

Although NASA manages its space science missions through divisions that correspond to scientific disciplines, Congress generally allocates funds through broader categories. From 1979 to 1988, NASA submitted its science budget requests and Congress allocated funds through three categories: physics and astronomy, lunar and planetary (called planetary exploration beginning in FY 1980), and life sciences. Each of these broad categories contained several line items that corresponded either to missions such as the space telescope or to activities such as research and analysis.

Some budget category titles exactly match mission names. Other missions that do not appear in the budget under their own names were reimbursable—that is, NASA was reimbursed by another agency for its services and expended minimal funds (relatively speaking) or no funds of its own. These minimal expenses were generally included in other budget categories, such as launch support or ground system support. Still other missions were in-house projects—the work was done primarily by civil servants funded by the Research and Program Management appropriation rather than the Research and Development appropriation. Other science missions could be found in the detailed budget data and the accompanying narratives that NASA's budget office issued. For instance, the FY 1983 Explorer Development budget category under the larger Physics and Astronomy category included the Dynamics Explorer, the Solar Mesosphere Explorer, the Infrared Astronomical Satellite, the Active Magnetospheric Particle Tracer Explorer, the Cosmic Background Explorer, and a category titled "Other Explorers." NASA described the Explorer program as a way of conducting missions with limited, specific objectives that did not require major observatories.

During the period addressed in this chapter, all the launched missions were included under the broad budget category of Physics and Astronomy. The Planetary Exploration budget category funded both the ongoing activities relating to missions launched prior to 1979 and those that would be launched beginning in 1989. The Life Sciences budget category funded many of the experiments that took place on the Space Shuttle and also funded NASA-sponsored experiments on the Spacelab missions. This budget category also paid for efforts directed at maintaining the health of Space Shuttle crews, increasing understanding of the effects of microgravity, and investigating the biosphere of Earth. Funds designated for life sciences programs also contributed heavily to the Space Station program effort.

Over this ten-year period, funding for space science roughly doubled. This almost kept pace with the increase in the total Research and

Development (R&D) and Space Flight, Control and Data Communications (SFC&DC) budgets, which slightly more than doubled. (The R&D appropriation was split into R&D and SFC&DC in 1984.) Thus, even though there were fewer missions over this ten-year period than in the prior ten years, if relative funding is a guide, NASA placed roughly the same importance on space science at the beginning of the decade that it did at its conclusion.

The figures in the tables following this chapter (Tables 4–1 through 4–23) show dollars that have not been inflated. If one considers inflation and real buying ability, then funding for space science remained fairly level over the decade.

Space Science Missions

Prior to the merger of NASA's OSS and OSTA in November 1981, missions could clearly be considered either space science or space applications. However, once the two organizations merged, a clear distinction was not always possible. This chapter includes activities formulated by NASA as space science missions and funded that way by Congress. It also includes science missions managed by other organizations for which NASA provided only launch services or some other nonscientific service.

The first subsection describes physics and astronomy missions, beginning with missions that were launched from 1979 to 1988. The next subsection covers on-board Shuttle missions during the decade. The third subsection contains physics and astronomy missions that were launched during the previous decade but continued to operate in these years and the missions that were under development during this decade but would not be launched until after 1988. The final subsection describes planetary missions—first those that were launched during the previous decade but continued to return data and then those being developed from 1979 to 1988 in preparation for launch after 1988. Table 4–24 lists each science mission that NASA either managed or had some other support role (indicated with an "*") and its corresponding discipline or management area.

Physics and Astronomy Program

The goal of NASA's Physics and Astronomy program was to add to what was already known about the origin and evolution of the universe, the fundamental laws of physics, and the formation of stars and planets. NASA conducted space-based research that investigated the structure and dynamics of the Sun and its long- and short-term variations; cosmic ray, x-ray, ultraviolet, optical, infrared, and radio emissions from stars, interstellar gas and dust, pulsars, neutron stars, quasars, black holes, and other celestial sources; and the laws governing the interactions and processes occurring in the universe. Many of the phenomena being investigated were not detectable from ground-based observatories because of the obscuring or distorting effects of Earth's atmosphere. NASA accomplished the objectives of the program with a mix of large, complex, free-flying space missions, less complex Explorer spacecraft, Shuttle and Spacelab flights, and suborbital activities.

Spacecraft Charging at High Altitudes

The Spacecraft Charging at High Altitudes mission was part of a U.S. Air Force program seeking to prevent anomalous behavior associated with satellites orbiting Earth at or near geosynchronous altitudes of 37,000 kilometers. NASA provided the launch vehicle and launch vehicle support as part of a 1975 agreement between OSS (representing NASA) and the Space and Missile Systems Organization (representing the Air Force). OSS also provided three scientific experiments. Each experiment investigated electrical static discharges that affected satellites in geostationary orbit. The experiments measured electrons, protons, and alpha particles, the surface charging and discharging of the satellite, and anomalous currents flowing through the spacecraft's wires at any given time. This mission's characteristics are listed in Table 4–25.

UK-6

The launch of UK-6 (also called Ariel) marked the one hundredth Scout launch. This was a fully reimbursable mission under the terms of a March 16, 1976, contract between NASA and the United Kingdom Science Research Council. NASA provided the launching and tracking services required for the mission. The project provided scientists with a large body of information about heavy nuclei. These invisible cosmic bullets supplied clues to the nature and origin of the universe. The experiments aboard the satellite examined cosmic rays and x-rays emitted by quasars, supernovas, and pulsars in deep space. UK-6's characteristics are in Table 4–26.

High Energy Astronomy Observatory-3

HEAO-3 was the third in a series of three Atlas-Centaur-launched satellites to survey the entire sky for x-ray sources and background of about one millionth of the intensity of the brightest known source, SCO X1. It also measured the gamma ray flux, determined source locations and line spectra, and examined the composition and synthesis of cosmic ray nuclei.

HEAO-3 carried three instruments that performed an all-sky survey of cosmic rays and gamma rays, similar to the earlier HEAO missions except at a higher orbital inclination. This higher orbital inclination allowed instruments to take advantage of the greater cosmic ray flux near Earth's magnetic poles. One objective was to measure the spectrum and intensity of both diffuse and discrete sources of x-ray and gamma ray radiation. In addition, HEAO-3 carried an instrument that observed high atomic number relativistic nuclei in the cosmic rays and measured the elemental composition and energy spectra of these nuclei to determine the abundance of the individual elements.

HEAO-3 operated until May 30, 1981, when it expended the last of its supply of thruster gases used for attitude control and was powered down. With twenty months of operating time in orbit, HEAO-3 became the third HEAO spacecraft to perform for more than twice its intended design life. Its characteristics are in Table 4–27; Figures 4–3 through 4–5 show diagrams of three HEAO instruments.

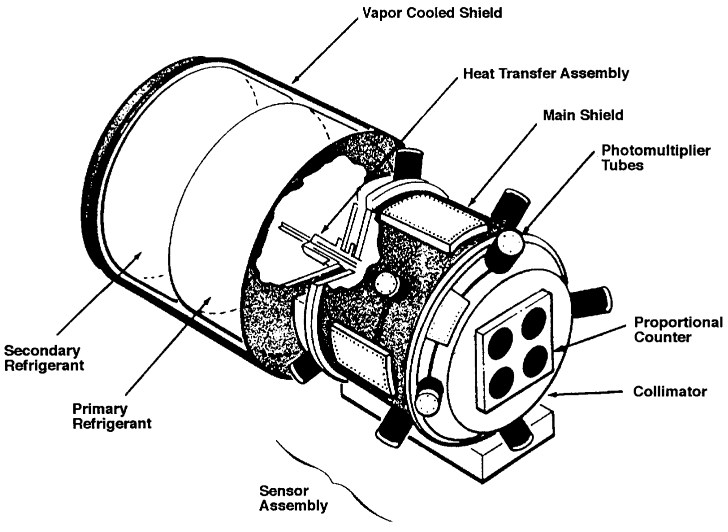


Figure 4–3. HEAO High-Spectral Resolution Gamma Ray Spectrometer

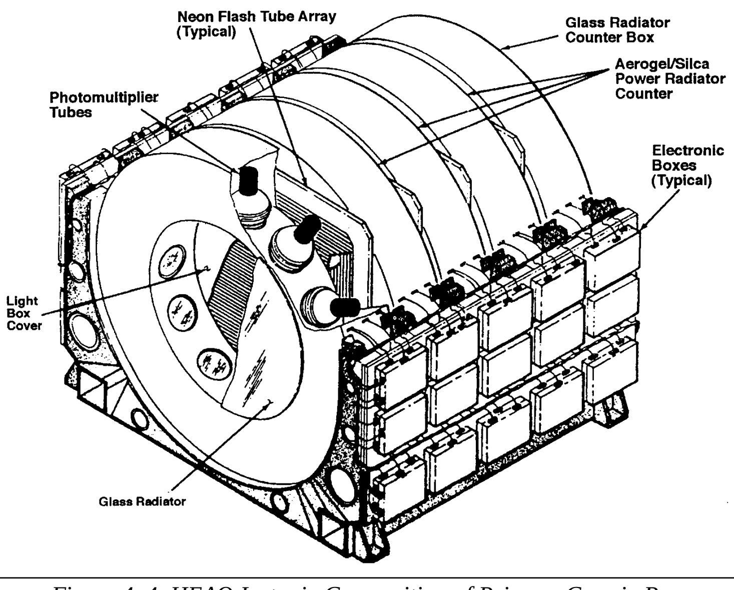


Figure 4–4. HEAO Isotopic Composition of Primary Cosmic Rays

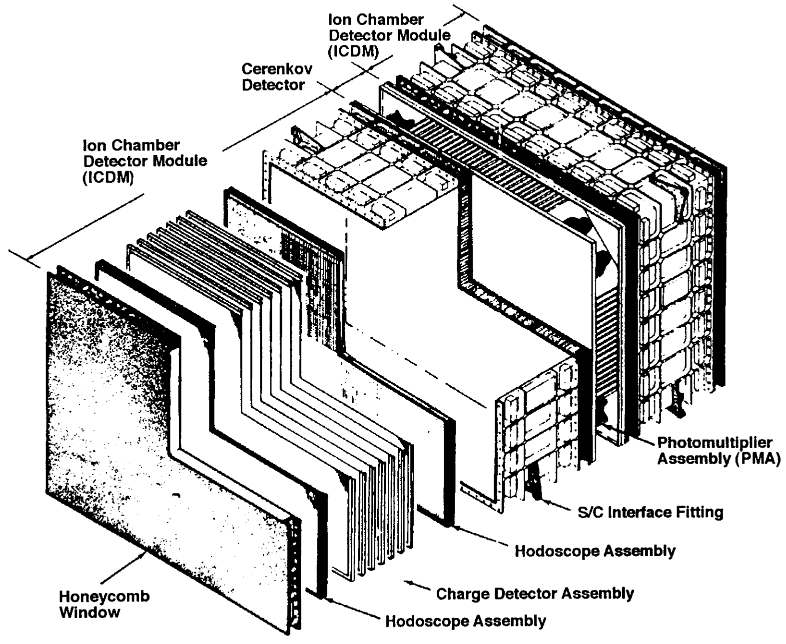


Figure 4–5. HEAO Heavy Nuclei Experiment

Solar Maximum Mission

The Solar Maximum Mission (also known as Solar Max) observatory was an Earth-orbiting satellite that continued NASA's solar observatory research program, which had begun in 1962. The satellite was a three-axis inertially stabilized platform that provided precise stable pointing to any region on the Sun to within five seconds of arc. The mission studied a specific set of solar phenomena: the impulsive, energetic events known as solar flares and the active regions that were the sites of flares, sunspots, and other manifestations of solar activity. Solar Max allowed detailed observation of active regions of the Sun simultaneously by instruments that covered gamma ray, hard and soft x-ray, ultraviolet, and visible spectral ranges. Table 4–28 lists the mission's characteristics, and Figure 4–6 contains a diagram of Solar Max's instruments.

Solar Max was part of an international program involving a worldwide network of observatories. More than 400 scientists from approximately sixty institutions in seventeen foreign nations and the United States participated in collaborative observational and theoretical studies of solar flares. In the solar science community, 1980 was designated the "Solar Maximum Year" because it marked the peak of sunspot activity in the Sun's eleven-year cycle of activity.

The first months of the mission were extremely successful. Careful

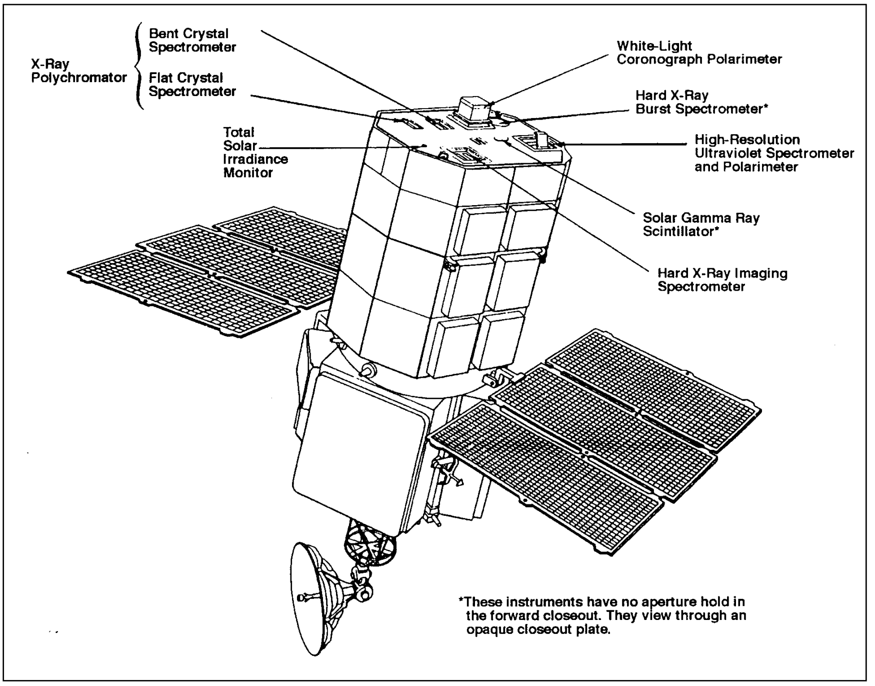


Figure 4–6. Solar Maximum Instruments

orchestration of the instruments resulted in the most detailed look at solar flares ever achieved. The instruments recorded hundreds of flares, and the cumulative new data base was unsurpassed. Solar Max instruments set new standards of accuracy and precision and led scientists to a number of firsts and new answers to old questions. However, nine months into the mission, fuses in the attitude control system failed, and the satellite lost its ability to point with fine precision at the Sun. Although a few instruments continued to send valuable data despite the loss of fine pointing, most of the instruments were useless, and those still operating lost the benefits of operating in a coordinated program. The mission was declared a success, however, because its operation, although abbreviated, fulfilled the success criteria established before launch. Nevertheless, its reduction from the expected two years to nine months meant a significant loss to solar science.

NASA designed Solar Max to be serviced in space by a Space Shuttle crew. Thus, in April 1984, the crew of STS 41-C successfully repaired Solar Max. Following its repair, Solar Max operated successfully until November 1989. A description of the STS 41-C repair mission is in Chapter 3.

Dynamics Explorer 1 and 2

The Dynamics Explorer 1 and 2 satellites provided data about the coupling of energy, electric currents, electric fields, and plasmas (ionized atomic particles) among the magnetosphere, the ionosphere, and the atmosphere. The two spacecraft worked together to examine the processes by which energy from the Sun flows through interplanetary space and entered the region around Earth, controlled by the magnetic forces from Earth's magnetic field, to produce the auroras (northern lights) that affect radio transmissions and possibly influence basic weather patterns.

The two satellites were stacked on a Delta launch vehicle and placed into coplanar (in the same plane but at different altitudes) orbits. Dynamics Explorer 1 was placed in a higher elliptical orbit than Dynamics Explorer 2. The higher orbit allowed for global auroral imaging, wave measurements in the center of the magnetosphere, and crossing of auroral field lines at several Earth radii. Dynamics Explorer 2's lower orbit allowed for neutral composition and temperature and wind measurements, as well as an initial apogee to allow measurements above the interaction regions for suprathermal ions and plasma flow measurements at the base of the magnetosphere field lines. The two satellites carried a total of fifteen instruments, which took measurements in five general categories:

- Electric field-induced convection
- Magnetosphere-ionosphere electric currents
- Direct energy coupling between the magnetosphere and the ionosphere
- Mass coupling between the ionosphere and the magnetosphere
- Wave, particle, and plasma interactions

The Dynamics Explorer mission complemented the work of two previous sets of satellites, the Atmosphere Explorers and the International Sun-Earth Explorers. The three Atmosphere Explorer satellites studied the effects of the absorption of ultraviolet light waves by the upper atmosphere at altitudes as low as a satellite can orbit (about 130 kilometers). The three International Sun-Earth Explorer satellites studied how the solar wind interacted with Earth's magnetic field to transfer energy and ionized charged particles into the magnetosphere. The Dynamics Explorer mission also was to set the stage for a fourth program planned for later in the 1980s that would provide a comprehensive assessment of the energy balance in near-Earth space. The mission's characteristics are in Table 4–29.

Solar Mesospheric Explorer

The Solar Mesospheric Explorer, launched in 1981, was part of the NASA Upper Atmospheric Research program. NASA developed this program under the congressional mandates in the FY 1976 NASA Authorization Act and the Clean Air Act Amendments of 1977. It focused on developing a solid body of knowledge of the physics, chemistry, and dynamics of the upper atmosphere. From an initial emphasis on assessments of the impacts of chlorofluoromethane releases, Shuttle exhausts, and aircraft effluents on stratospheric ozone, the program evolved into extensive field measurements, laboratory studies, theoretical developments, data analysis, and flight missions.

The Solar Mesospheric Explorer was designed to supply data on the nature and magnitude of changes in the mesospheric ozone densities that resulted from changes in the solar ultraviolet flux. It examined the interrelationship between ozone and water vapor and its photo dissociation products in the mesosphere and among ozone, water vapor, and nitrogen dioxide in the upper stratosphere.

The University of Colorado's Laboratory for Atmospheric and Space Physics provided the science instruments for this mission. The laboratory, under contract to the Jet Propulsion Laboratory, was also responsible for the observatory module, mission operations, the Project Operations Control Center, and science data evaluation and dissemination. Ball Aerospace's Systems Division provided the spacecraft bus and satellite integration and testing. The science team was composed of seventeen members from four institutions. A science data processing system, located at the Laboratory for Atmospheric and Space Physics, featured an online central processing and analysis system to perform the majority of data reduction and analysis for the science investigations.

The spacecraft consisted of two sections (Figure 4–7). The spacecraft bus carried communication, electrical, and command equipment. A notable feature was the 1.25-meter diameter disc used for mounting the 2,156 solar cells directed toward the Sun to feed power into the two nickel cadmium batteries. A passive system that used insulating material and a network of stripes on the outer surface kept internal temperatures within limits. The satellite body was spin-stabilized.

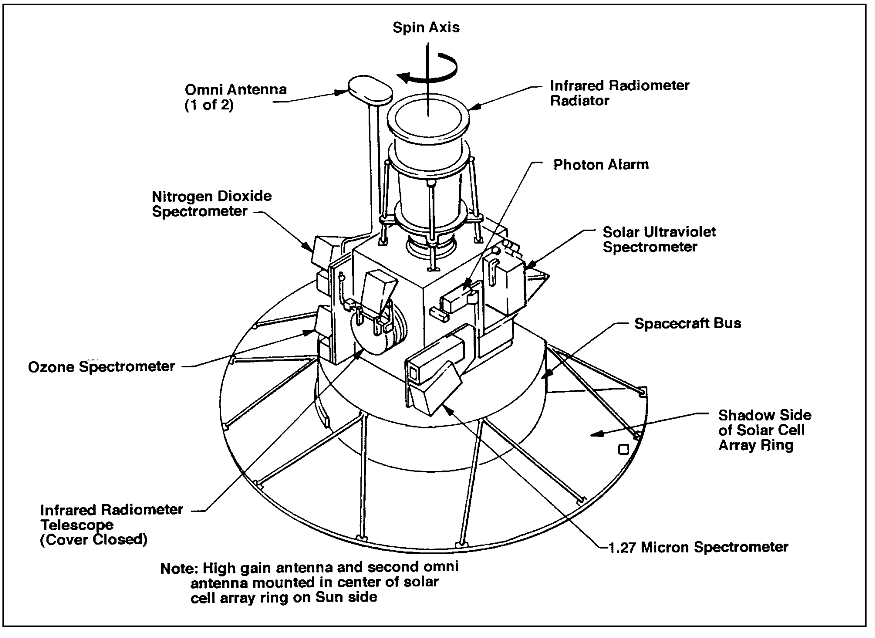


Figure 4–7. Solar Mesospheric Explorer Satellite Configuration

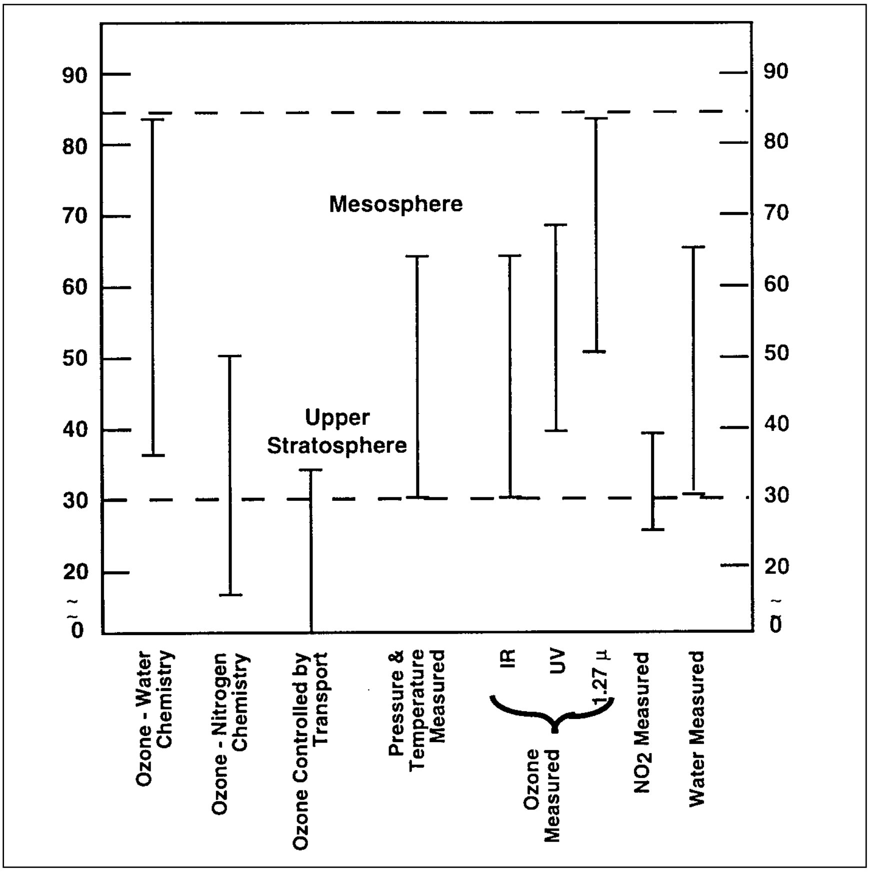


Figure 4–8. Altitude Regions to Be Measured by Solar Mesospheric Explorer Instruments

The observatory module carried the instruments. Four limb scanning instruments measured ozone, water vapor, nitrogen dioxide, temperature, and pressure in the upper stratosphere and mesosphere at particular altitudes (Figure 4–8). Two additional instruments monitored the Sun. The Solar Mesospheric Explorer spun about its long axis at ninety degrees to its orbital plane so that on every turn, the instruments scanned the atmosphere on the horizon between twenty and eighty kilometers. Data from the rotating science instruments are gated (cycled "on") once each revolution. Table 4–30 lists the characteristics of each instrument, and Table 4–31 lists the mission's characteristics.

Infrared Astronomy Satellite

The Infrared Astronomy Satellite (IRAS) was the second Netherlands-United States cooperative satellite project, the first being the Astronomical Netherlands Satellite launched in 1974. A memorandum of understanding between the Netherlands Agency for Aerospace Programs and NASA established the project on October 4, 1977. The United Kingdom also participated in the program under a separate memorandum of understanding between the United Kingdom's Science and Engineering Research Council and the Netherlands Agency for Aerospace Programs.

Under the terms of the memorandum of understanding, the United States provided the infrared telescope system, the tape recorders, the Delta launch vehicle, the scientific data processing, and the U.S. co-chair and members of the Joint IRAS Science Working Group. The Netherlands Agency for Aerospace Programs provided the other co-chair and European members of the Joint IRAS Science Working Group, the spacecraft, the Dutch additional experiment (DAX), and the integration, testing, and launch preparations for the flight satellite. The Netherlands Agency for Aerospace Programs and the Science and Engineering Research Council provided spacecraft command and control and primary data acquisition with a ground station and control center located at Chilton, England. The United States provided limited tracking, command, and data acquisition by stations in the NASA Ground Spacecraft Tracking and Data Network.

IRAS was the first infrared satellite mission. It produced an all-sky survey of discrete sources in the form of sky and source catalogues using four broad photometry channels between eight and 120 micrometers. The mission performed the all-sky survey, provided additional observations on the more interesting known and discovered sources, and analyzed the data.

The satellite system consisted of two major systems: the infrared telescope and the spacecraft (Figure 4–9). The infrared telescope system consisted of the telescope, cryogenics equipment, electronics, and a focal-plane detector array. The detector array consisted of a primary set

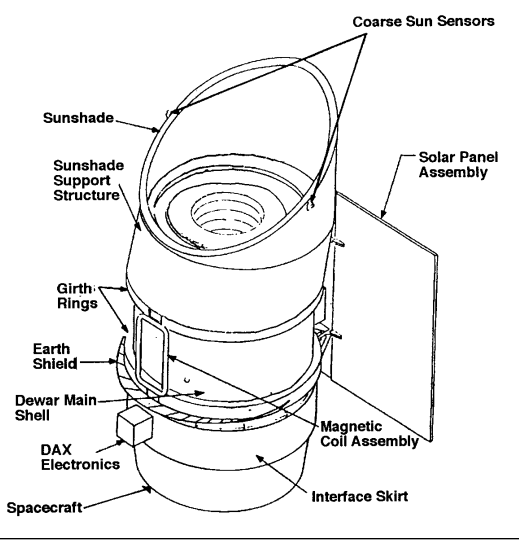


Figure 4–9. Infrared Astronomy Satellite Configuration

of infrared detectors, a set of photodiodes for use as aspect sensors, and a DAX. The DAX comprised a low-resolution spectrometer, a chopped photometric channel, and a short wavelength channel. The spacecraft provided the support functions of electrical power, attitude control, computing, and telecommunications.

During its all-sky survey, IRAS observed several important phenomena. It detected a new comet, named Comet IRAS-Araki-Alcock (1983d), which was distinguished by its very close approach to Earth, 5 million kilometers on May 11, 1983, the closest approach to Earth of a comet in 200 years. IRAS discovered a second, extremely faint comet (1983f) on May 12. This comet was a million times fainter than the first and was leaving the solar system. IRAS also discovered very young stars (protostars) no more than a million years old. It also observed two closely interacting galaxies that were being disrupted by each other's gravitational forces. IRAS made approximately 200,000 observations and transmitted more than 200 billion bits of data, which scientists have continued to examine and analyze.

IRAS revolutionized our understanding of star formation, with observations of protostars and of interstellar gas in star-forming regions. It discovered the "interstellar cirrus" of wispy cool far-infrared emitting dust throughout our galaxy. It discovered infrared emissions in spiral galaxies, including a previously unknown class of "ultraluminous infrared galaxies" in which new stars were forming at a very great rate. IRAS also showed that quasars emit large amounts of far-infrared radiation, suggesting the presence of interstellar dust in the host galaxies of those objects.

IRAS operated successfully until November 21, 1983, when it used the last of the super-fluid helium refrigerant that cooled the telescope. IRAS represented as great an improvement over ground-based telescopes as the Palomar 200-inch telescope was over Galileo's telescope. The unprecedented sensitivity of IRAS provided a survey of a large, unexplored gap in the electromagnetic spectrum. The international IRAS science team compiled a catalogue of nearly 250,000 sources measured at four infrared wavelengths—including approximately 20,000 new galaxies and 16,000 small extended sources—and the Jet Propulsion Laboratory's Infrared Processing and Analysis Center produced IRAS Sky Maps. IRAS successfully surveyed more than 96 percent of the sky. Its mission characteristics are in Table 4–32.

The Plasma Interaction Experiment (PIX-II) also rode on the Delta launch vehicle that deployed IRAS. A Lewis Research Center investigation, PIX-II evaluated the effects of solar panel area on the interactions between the space charged-particle environment and surfaces at high potentials (+/–one keV). PIX-II was the second experiment to investigate the effects of space plasma on solar arrays, power system conductors, insulators, and other exposed spacecraft components. The experiment remained with the second stage of the Delta launch vehicle in orbit at an altitude of 640 kilometers. Data from PIX-II were transmitted to two tracking stations.

European X-Ray Observatory Satellite

NASA launched the European X-Ray Observatory Satellite (EXOSAT) for the European Space Agency (ESA), which reimbursed NASA for the cost of providing standard launch support in accordance with the terms of a launch services agreement signed March 25, 1983. A Delta 3914 placed the satellite in a highly elliptical orbit that required approximately four days to complete. This orbit provided maximum observation periods, up to eighty hours at a time, while keeping the spacecraft in full sunlight for most of the year, thereby keeping thermal conditions relatively stable and simplifying alignment procedures. The orbit also allowed practically continuous coverage by a single ground station.

EXOSAT supplied detailed data on cosmic x-ray sources in the soft x-ray band four one-hundredths keV to eighty keV. The principal scientific objectives involved locating x-ray sources and studying their spectroscopic and temporal characteristics. The location of x-ray sources was determined by the use of x-ray imaging telescopes. The observatory also mapped diffuse extended sources such as supernova remnants and resolve sources within nearby galaxies and galaxies within clusters. The spacecraft performed broad-band spectroscopy, or “color” cataloguing of x-ray sources, and studied the time variability of sources over time scales ranging from milliseconds to days.

The EXOSAT observatory was a three-axis stabilized platform with an inherent orbit correction capability. It consisted of a central body covered with super-insulating thermal blankets and a one-degree-of-freedom rotatable solar array. The platform held the four experiments, which were co-aligned with the optical axis defined by two star trackers, each mounted on an imaging telescope (Figure 4–10). Table 4–33 contains the mission’s characteristics.

Shuttle Pallet Satellite

The Shuttle Pallet Satellite (SPAS)-01 was a reusable platform built by the German aerospace firm Messerschmitt-Bolkow-Blohm (MBB) and carried on STS-7 as part of an agreement with MBB. The agreement provided that, in return for MBB’s equipping SPAS-01 for use in testing the deployment and retrieval capabilities of the remote manipulator arm, NASA would substantially reduce the launching charge for SPAS-01. The platform contained six scientific experiments from the West German Federal Ministry of Research and Technology, two from ESA, and three from NASA along with several cameras.

The first satellite designed to be recaptured by the Shuttle’s robot arm, SPAS-01 operated both inside and outside the orbiter’s cargo bay. In the cargo bay, the satellite demonstrated its system performance and served as a mounted platform for operating scientific experiments. Seven scientific experiments were turned on during the third day of the flight and ran continuously for about twenty-four hours.

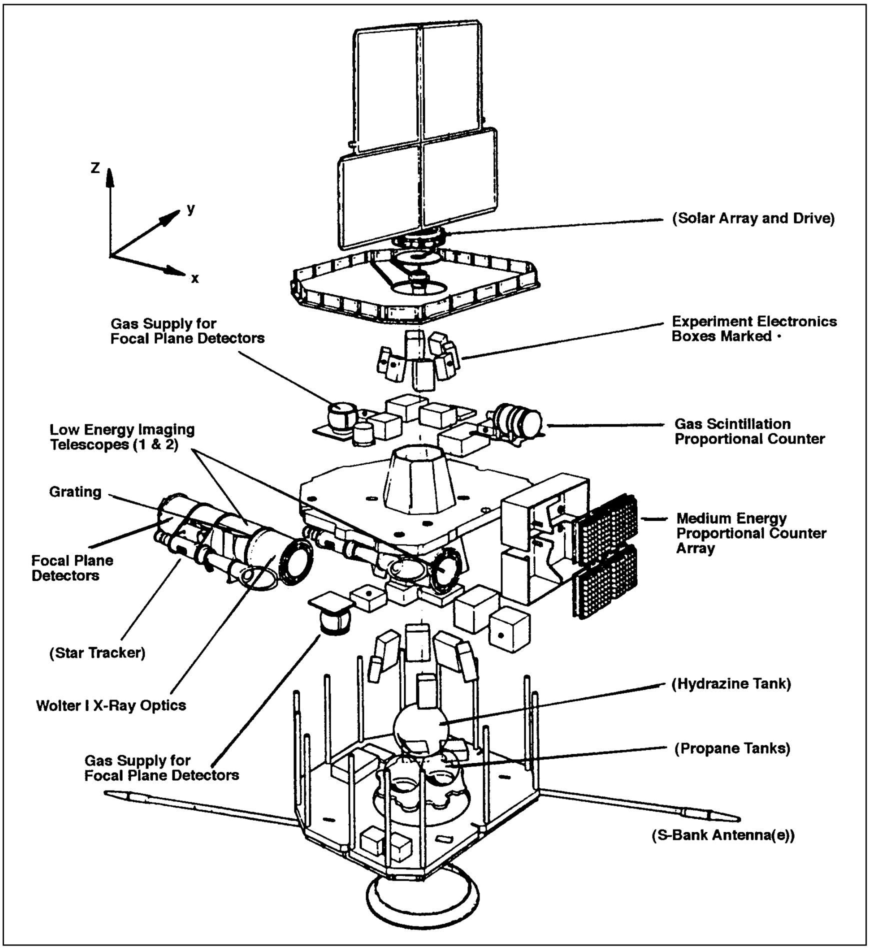


Figure 4–10. Exploded View of the European X-Ray Observatory Satellite

In the free-flyer mode, SPAS-01 was used as a test article to demonstrate the orbiter's capability to deploy and retrieve satellites in low-Earth orbit. During this phase of the mission, crew members operated two German and three NASA experiments. MBB built the platform to demonstrate how spaceflights could be used for private enterprise purposes. The West German Federal Ministry of Research and Technology supported the SPAS-01 pilot project and contributed to mission funding. Mission characteristics are in Table 4–34.

Hilat

The Air Force developed Hilat to gather data on ionospheric irregularities and auroras (northern lights) in an effort to improve the effectiveness of Department of Defense communications systems. The interaction of charged particles, ionized atmospheric gases, and magnetic fields can degrade radio communications and radar system performance at high latitudes. Four of the five experiments on board were sponsored by the Defense Nuclear Agencies. They measured turbulence caused by ionospheric irregularities and observed electron, ion, proton, and magnetic activity. The fifth experiment, sponsored by the Air Force Geophysics Laboratory at Hanscom Air Force Base, used an auroral ionospheric mapper to gather imagery of the auroras. NASA was reimbursed for launch services. Table 4–35 contains the mission's characteristics.

Active Magnetospheric Particle Tracer Explorers

The Active Magnetospheric Particle Tracer Explorers (AMPTE) project investigated the transfer of mass from the solar wind to the magnetosphere and its further transport and energization within the magnetosphere. It attempted to establish how much of this immense flow from the Sun, which sometimes affected the performance of electronic systems aboard satellites, entered the magnetosphere and where it went. AMPTE mission objectives were to:

- Investigate the entry of solar wind ions to the magnetosphere
- Study the transport of magnetotail plasma from the distant tail to the inner regions of the magnetosphere
- Study the interaction between an artificially injected plasma and the solar wind
- Establish the elemental and charge composition of energetic charge particles in the equatorial magnetosphere

The scientific experiments carried aboard the three AMPTE satellites (described below) helped determine the number and energy spectrum of solar wind ions and, ultimately, how they gained their high energies. Figure 4–11 illustrates the distortion of Earth's magnetic field into the magnetosphere.

AMPTE also investigated the interaction of two different flowing plasmas in space, another common astronomical phenomenon. AMPTE studied in detail the local disturbances that resulted when a cold dense plasma was injected and interacted with the hot, rapidly flowing natural plasmas of the solar wind and magnetosphere. The AMPTE spacecraft injected tracer elements into near-Earth space and then observed the motion and acceleration of those ions. One expected result was the formation of artificial comets, which were observed from aircraft and from the ground. In this respect, AMPTE's active interaction with the environment made it different from previous space probes, which had passively measured their surrounding environment.

This international cooperative mission consisted of three spacecraft: (1) a German-provided Ion Release Module (IRM), which injected artificial tracer ions (lithium and barium) inside and outside Earth's magnetosphere; (2) a U.S.-provided Charge Composition Explorer (CCE), which detected and monitored these ions as they convected and diffused

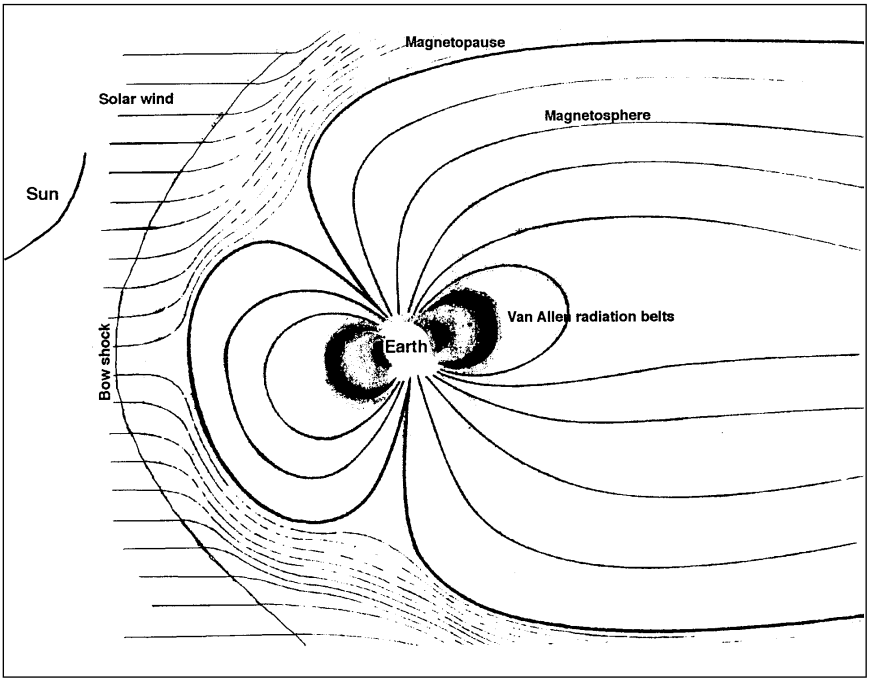


Figure 4–11. Distortion of Earth's Magnetic Field
(The solar wind distorts Earth's magnetic field, in some cases pushing field lines from the day side of Earth back to the night side.)

through the inner magnetosphere; and (3) a United Kingdom-provided subsatellite (UKS), which detected and monitored these ions within a few hundred kilometers of the release point. Each of the spacecraft contributed to the achievement of the mission objectives. The IRM released tracer ions in the solar wind and attempted to detect them with the CCE inside the magnetosphere. This was done four times under different solar wind conditions and with different tracer ions.

The IRM also released barium and lithium ions into the plasma sheet and observed their energy spectrum at the CCE. Four such releases took place. In addition to the spacecraft observations, ground stations and aircraft in the Northern and Southern Hemispheres observed the artificial comet and tail releases. No tracer ions were detected in the CCE data, a surprising result, because, according to accepted theories, significant fluxes of tracer ions should have been observed at the CCE. However, in the case of the last two tail releases, the loss of the Hot Plasma Composition Experiment instrument on April 4, 1985, severely restricted the capability of the CCE to detect low-energy ions. The spacecraft also formed two barium artificial comets. In both instances, a variety of ground observation sites in the Northern and Southern Hemispheres obtained good images of these comets.

Observations relating to the composition, charge, and energy spectra of energetic particles in the near equatorial orbit plane of the CCE were to occur for a period of at least six months. With the exception of the Hot Plasma Composition Experiment, the instruments on board the CCE acquired the most comprehensive and unique data set on magnetospheric ions ever collected. For the first time, the ions that made up the bulk of Earth's ring current were identified, their spectrum determined, and dynamics studied. Several major magnetic storms that occurred during the first year of operation allowed measurements to be taken over a wide range of magnetic activity indices and solar wind conditions.

The three AMPTE spacecraft were launched into two different orbits. A Delta launch vehicle released the three satellites in a stacked fashion. The CCE separated first from the group of three, and the IRM and UKS remained joined. The CCE on-board thrusters fired to position the satellite in Earth's equatorial plane. About eight hours later, the IRM fired an on-board rocket to raise the IRM/UKS orbit apogee to twice its initial value. The two satellites then separated, and for the remainder of the mission, small thrusters on the UKS allowed it to fly in close formation with the IRM satellite. Tables 4–36, 4–37, and 4–38 list the specific orbit characteristics of the three satellites.

Spartan 1

Spartan 1 was the first of a continuing series of low-cost free-flyers designed to extend the observing time of sounding-rocket-class experiments from a few minutes to several hours. The Astrophysics Division of NASA's OSSA sponsored the satellite. The Naval Research Laboratory provided the scientific instrument through a NASA grant. The instrument, a medium-energy x-ray scanner, had been successfully flown several times on NASA sounding rockets. It scanned the Perseus Cluster, Galactic Center, and Scorpius X-2 to provide x-ray data over the energy range of a half keV to fifteen keV (Figure 4–12).

The June 1985 launch was NASA's second attempt to launch Spartan 1. It had previously been manifested on STS 41-F for an August 1984 flight, but was demanifested because of problems with the launch of *Discovery.*

Researchers could use the Spartan family of reusable satellites for a large variety of astrophysics experiments. The satellites were designed to be deployed and retrieved by the Shuttle orbiter using the remote manipulator system. Once deployed, the Spartan satellite could perform scientific observations for up to forty hours. All pointing sequences and satellite control commands were stored aboard the Spartan in a microcomputer controller. A 10^{10}-bit tape recorder recorded all data, and no command or telemetry link was provided. Once the Spartan satellite completed its observations, it "safed" all systems and placed itself in a stable attitude to allow for retrieval by the orbiter and a return to Earth for data analysis and preparation for a new mission. Table 4–39 lists Spartan 1's mission characteristics.

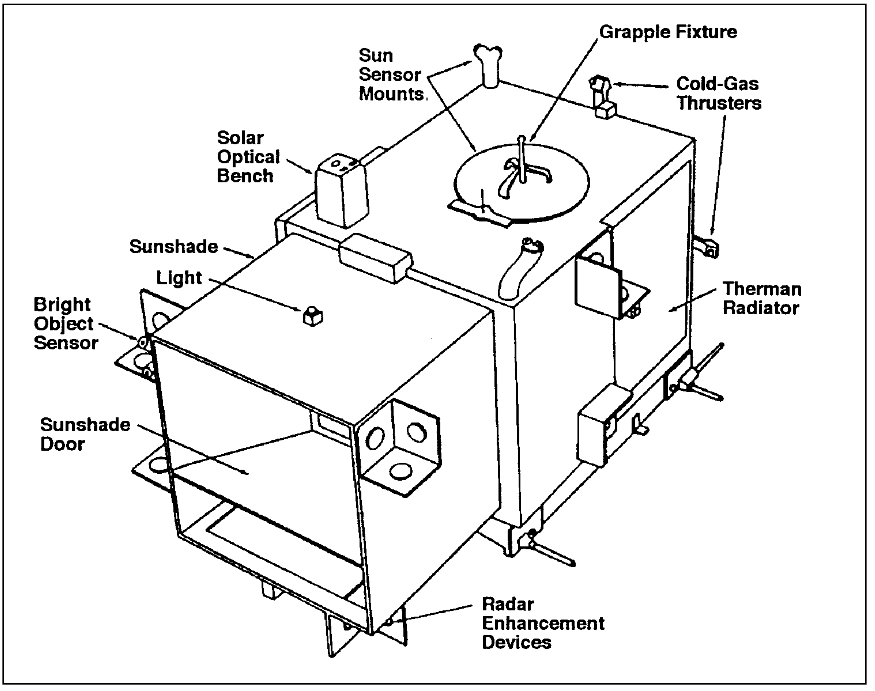


Figure 4–12. Spartan 1

Plasma Diagnostic Package

The Plasma Diagnostics Package (PDP) flew on two Shuttle missions—STS-3 as part of the OSS-1 payload and STS 51-F as part of the Spacelab 2 mission. On its first flight, it made measurements while mounted in the Shuttle payload bay and while suspended from the remote manipulator arm. It successfully measured electromagnetic noise created by the Shuttle and detected other electrical reactions taking place between the Shuttle and the ionospheric plasma.

On STS 51-F, the PDP made additional measurements near the Shuttle and was also released as a free-flyer on the third day of the mission to measure electric and magnetic fields at various distances from the orbiter. During the maneuvers away from the Shuttle, called a "fly-around," a momentum wheel spun the satellite to fix it in a stable enough position for accurate measurements. As the orbiter moved away to a distance of approximately a half kilometer, an assembly of instruments mounted on the PDP measured various plasma characteristics, such as low-energy electron and proton distribution, plasma waves, electric field strength, electron density and temperature, ion energy and direction, and pressure of unchanged atoms. This was the first time that ambient plasma was sampled so far from the Shuttle. The survey helped investigators determine how far the orbiter's effects extended. Figure 4–13 illustrates PDP experiment hardware, and Table 4–40 describes characteristics of the PDP on STS 51-F. PDP characteristics on STS-3 were very similar.

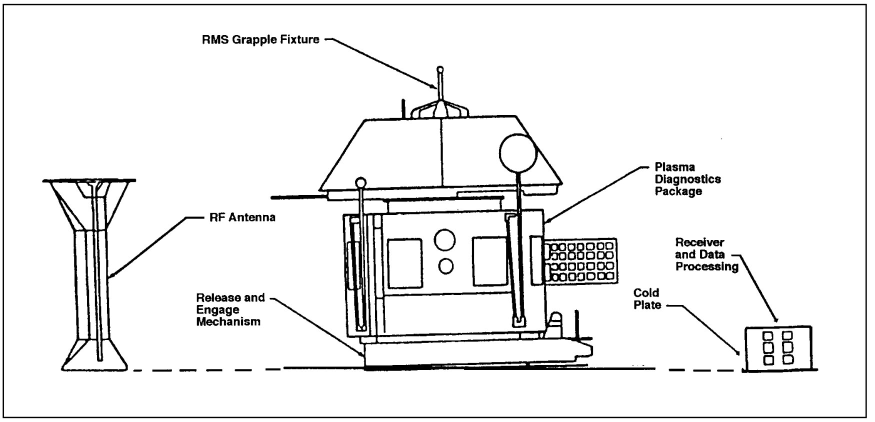


Figure 4–13. Plasma Diagnostics Package Experiment Hardware

Spartan 203 (Spartan Halley)

Spartan 203 was one of the STS 51-L payloads aboard *Challenger* that was destroyed in January 1986. Spartan Halley, the second in NASA's continuing series of low-cost free-flyers, was to photograph Halley's comet and measure its ultraviolet spectrum during its forty hours of flight in formation with the Shuttle. The spacecraft was to be deployed during the second day of the flight and retrieved on the fifth day. Both operations would use the remote manipulator system. The instruments being used had flown on sounding rockets as well as on the Mariner spacecraft. The mission was to take advantage of Comet Halley's location of less than 107.8 million kilometers from the Sun during the later part of January 1986. This period was scientifically important because of the increased rate of sublimation as the comet neared perihelion, which would occur on February 9. As Halley neared the Sun, temperatures would rise, releasing ices and clathrates, compounds trapped in ice crystals.

NASA's Goddard Space Flight Center and the University of Colorado's Laboratory for Atmospheric and Space Physics recycled several instruments and designs to produce a low-cost, high-yield spacecraft. Two spectrometers, derived from backups for a Mariner 9 instrument that studied the Martian atmosphere in 1971, were rebuilt to survey the comet in ultraviolet light from 128- to 340-nanometer wavelength. The spectrometers were not to produce images but would reveal the comet's chemistry through the ultraviolet spectral lines they recorded. From these data, scientists would have gained a better understanding of how (1) chemical structure of the comet evolved from the coma and proceeded down the tail, (2) species changed with relation to sunlight and dynamic processes within the comet, and (3) dominant atmospheric activities at perihelion related to the comet's long-term evolution. Figure 4–14 shows the Spartan Halley configuration, and Table 4–41 lists the mission's characteristics.

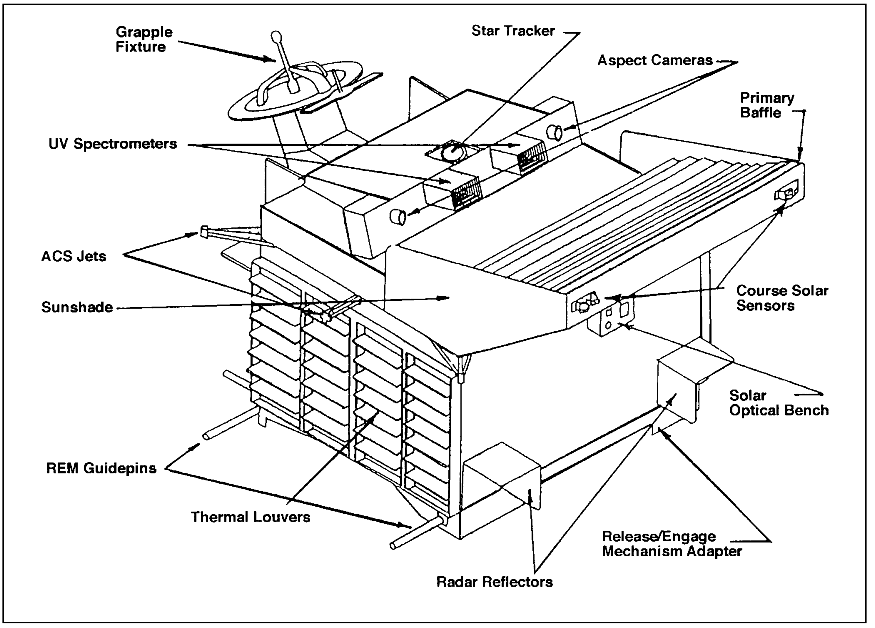


Figure 4–14. Spartan Halley Configuration

Polar BEAR

The Polar Beacon Experiments and Auroral Research satellite (Polar BEAR) mission, a follow-on to the 1983 Hilat mission, conducted a series of experiments for the Department of Defense that studied radio interference caused by the Aurora Borealis. Launched by NASA on a Scout launch vehicle, the satellite had hung in the Smithsonian for more than fifteen years. The retooled Oscar 17 satellite was built in the mid-1960s by the Navy as a spare but never launched. Polar BEAR's characteristics are in Table 4–42.

San Marco D/L

The San Marco D/L spacecraft, one element of a cooperative satellite project between Italy and the United States, explored the relationship between solar activity and meteorological phenomena, with emphasis on lower atmospheric winds of the equatorial thermosphere and ionosphere. This information augmented and was used with data obtained from ground-based facilities and other satellites. The San Marco D/L project was the fifth mission in a series of joint research missions conducted under an agreement between NASA and the Italian Space Commission. The first memorandum of understanding (MOU) between Italy's Italian Commissione per le Ricerche Spaziali and NASA initiated the program in May 1962. The first flight under this agreement took place in March 1964 with the successful launch by the Centro Ricerche Aerospaziali of a two-stage Nike sounding rocket from the Santa Rita launch platform off Kenya's coast. This vehicle carried the basic elements of the San Marco science instrumentation, flight-qualified the components, and provided a means of checking out range instrumentation and equipment.

This launch was followed by the December 1964 launch of the fully instrumented San Marco-I spacecraft from Wallops Island, Virginia. This marked the first time in NASA's international cooperative program that a satellite launch operation had been conducted by a non-U.S. team and the first use of a satellite fully designed and built in Western Europe. This launch also qualified the basic spacecraft design and confirmed the usefulness and reliability of the drag balance device for accurate determinations of air density values and satellite attitude.

Implementation of the agreement continued with the launch of San Marco-II into an equatorial orbit from the San Marco platform off the coast of Kenya in April 1967. This was the first satellite to be placed into equatorial orbit. The San Marco-II carried the same instrumentation as the San Marco-I, but the equatorial orbit permitted a more detailed study of density variations versus altitude in the equatorial region. The successful launch also qualified the San Marco range as a reliable facility for future satellite launches.

A second MOU between Centro Ricerche Aerospaziali and NASA signed in November 1967 provided for continued cooperation in satellite measurements of atmospheric characteristics and the establishment of the San Marco C program. The effort enhanced and continued the drag balance studies of the previous projects and initiated complementary mass spectrometer investigations of the equatorial neutral particle atmosphere. This phase enabled simultaneous measurements of atmospheric density from one satellite by three different techniques: direct particle detection, direct drag, and integrated drag. The San Marco C1 was launched on April 24, 1971, and the San Marco C2 was launched on February 18, 1974, both from the San Marco platform. The platform had also been used earlier in 1970 to launch Uhuru, an Explorer satellite that scanned 95 percent of the celestial sphere for sources of x-rays. It discovered three new pulsars that had not previously been identified.

NASA and Centro Ricerche Aerospaziali signed a third MOU in August 1974, continuing and extending their cooperation in satellite measurements of atmospheric characteristics and establishing the San Marco/Atmosphere Explorer Cooperative Project. This effort measured diurnal variations of the equatorial neutral atmosphere density, composition, and temperature for correlation with the Explorer 51 data for studies of the physics and dynamics of the thermosphere.

The San Marco D MOU was signed by Centro Ricerche Aerospaziali in July 1976 and by NASA in September 1976. This MOU assigned project management responsibility for the Italian portion of the project to Centro Ricerche Aerospaziali, while the Goddard Space Flight Center assumed project responsibility for the U.S. portion. There was also an

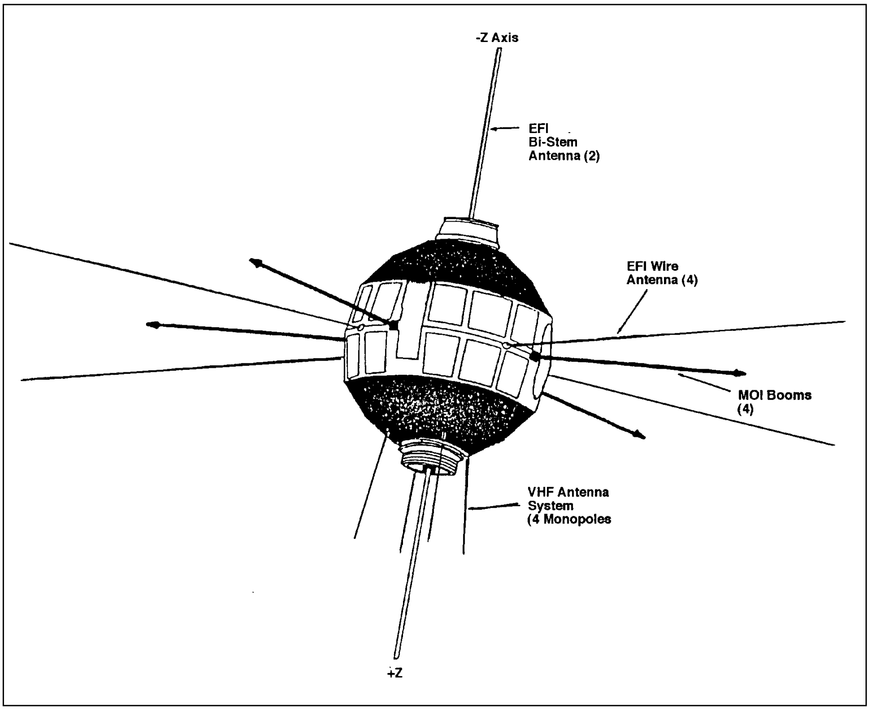


Figure 4–15. San Marco D/L Spacecraft

auxiliary cooperative agreement between the University of Rome and the Deutsche Forschungs Versuchsanstat für Luft und Raumfahrt (DFVLR) of the Federal Republic of Germany. This activity would explore the possible relationship between solar activity and meteorological phenomena to further define the structure, dynamics, and aeronomy of the equatorial thermosphere. Although initially both a low-orbit and an upper orbit spacecraft were planned, the program was reduced to a single spacecraft program—the low-orbit San Marco D/L (Figure 4–15).

In accordance with the MOU, the Centro Ricerche Aerospaziali provided the spacecraft, its subsystems, and an air drag balance system. The Deutsche Forschungs Versuchsanstat fur Luft und Raumfahrt provided an airglow solar spectrometer. NASA provided an ion velocity instrument, a wind/temperature spectrometer, and an electric field instrument. NASA also provided the Scout launch vehicle and technical and consultation support to the Italian project team. Mission characteristics of the San Marco D/L are in Table 4–43.

Attached Shuttle Payload Bay Science Missions

Beginning with the launch of STS-1 in April 1981, NASA had an additional platform available for performing scientific experiments. No longer did it have to deploy a satellite to obtain the benefits of a microgravity environment. Now, the payload bay on the Space Shuttle could provide this type of environment. NASA used these surroundings for a variety of smaller experiments, small self-contained payloads, and large experimental missions. These larger missions were sponsored by NASA's OSS, OSTA, OSSA, and Office of Aeronautics and Space Technology (OAST). This chapter addresses the OSS and OSSA missions (the Spacelab missions). The OSTA missions are included in Chapter 2, "Space Applications," and the mission sponsored by OAST is discussed in Chapter 3, "Aeronautics and Space Research and Technology," both in Volume VI of the *NASA Historical Data Book.*

Spacelab Missions

NASA conducted three joint U.S./ESA Spacelab missions. Spacelab 1 (STS-9) and Spacelab 2 (STS 51-G) were verification flights. Spacelab 3 (STS 51-B) was an operational flight. Spacelab 1 was the largest international cooperative space effort yet undertaken and concluded more than ten years of intensive work by some fifty industrial firms and ten nations. Spacelab 1 cost the ESA approximately $1 billion. NASA also flew the first Spacelab reimbursable flight, Deutschland-1 (D-1), on STS 61-A in 1985. Table 4–44 provides a chronology of Spacelab development prior to the first Spacelab mission. Tables 4–45 through 4-48 supply details of the experiments flown on each mission.

Spacelab 1. The Spacelab 1 mission, which flew on STS-9, exemplified the versatility of the Space Shuttle. Payload specialist Ulf Merbold of ESA summed up the mission: "That was science around the clock and round the earth."[8] Payload specialists conducted science and applications investigations in stratospheric and upper atmospheric physics, materials processing, space plasma physics, biology, medicine, astronomy, solar physics, Earth observations, and lubrication technology. The broad discipline areas included atmospheric physics and Earth observations, space plasma physics, astronomy and solar physics, material sciences and technology, and life sciences (Table 4–45).

Atmospheric physics and Earth observations, space plasma physics, and solar physics investigators used the Spacelab 1 orbiting laboratory to study the origin and influence of turbulent forces that sweep by Earth causing visible auroral displays and disturbing radio broadcasts, civilian and military electronics, power distribution, and satellite systems. The astronomy investigations studied astronomical sources in the ultraviolet and x-ray wavelengths. These wavelengths were not observable on Earth because of absorption by the ionosphere or ozone layer. The materials science and technology investigations demonstrated the capability of Spacelab as a technological development and test facility. The experi-

[8]"Spacelab Utilization Future Tasks," *MBB/ERNO Report*, Vol. 9, No. 1, April 1984, p. 8, NASA Historical Reference Collection, NASA Headquarters, Washington, DC.

ments in this group took advantage of the microgravity conditions to perform studies on materials and mechanisms that are adversely affected on Earth by gravity. The life sciences investigations studied the effects of the space environment (microgravity and high-energy radiation) on human physiology and on the growth, development, and organization of living systems. Figures 4–16, 4–17, and 4–18 show the locations of the Spacelab 1 experiments.

Spacelab 3. Spacelab 3, conducted on STS 51-B, was the first operational Spacelab mission. It used several new mini-laboratories that would be used again on future flights. Investigators evaluated two crystal growth furnaces, a life support and housing facility for small animals, and two types of apparatus for the study of fluids on this flight. Most of the experiment equipment was contained inside the laboratory, but instruments that required direct exposure to space were mounted outside in the open payload bay of the Shuttle. Figure 4–19 shows the experiment module layout, and Table 4–46 lists Spacelab 3's experiments.

Materials science was a major thrust of Spacelab 3. Spacelab served as a microgravity facility in which processes could be studied and materials produced without the interference of gravity. A payload specialist with special expertise in crystal growth succeeded in producing the first crystal grown in space. Studies in fluid mechanics also took advantage of the microgravity environment. Investigations proved the concept of "containerless" processing for materials science experiments with the successful operation of the Drop Dynamics Module.

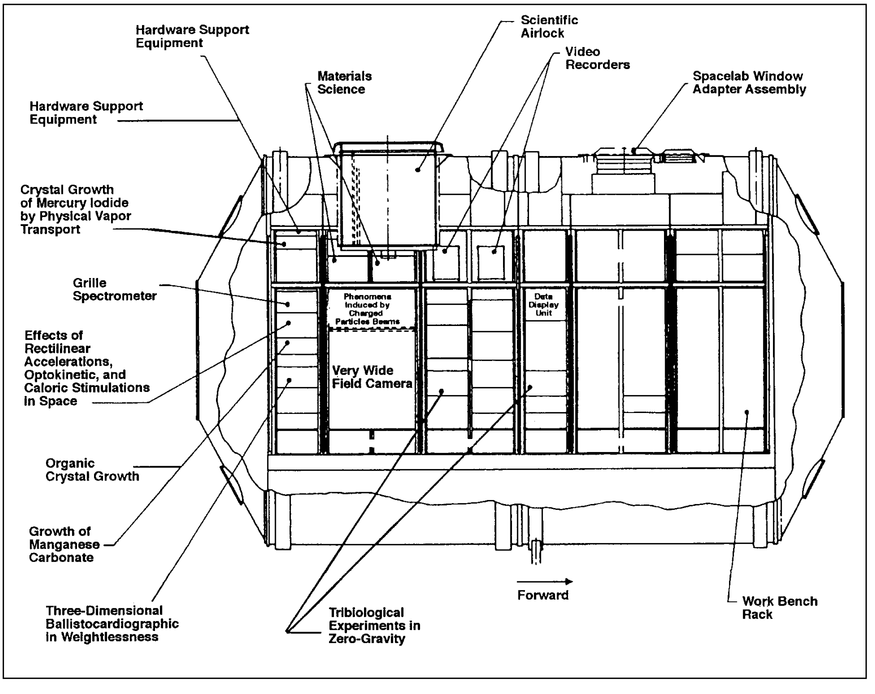


Figure 4–16. Spacelab 1 Module Experiment Locations (Port Side)

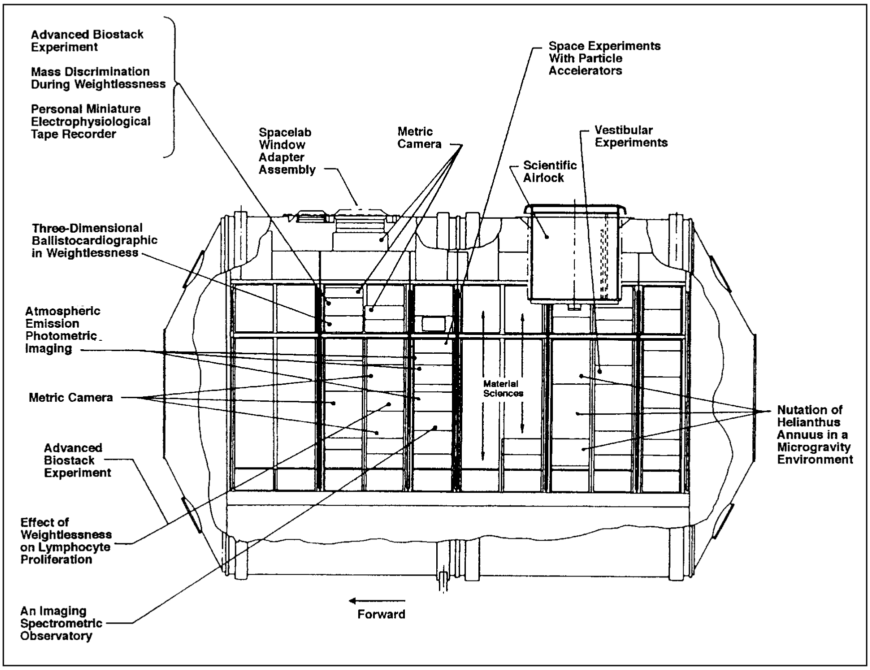
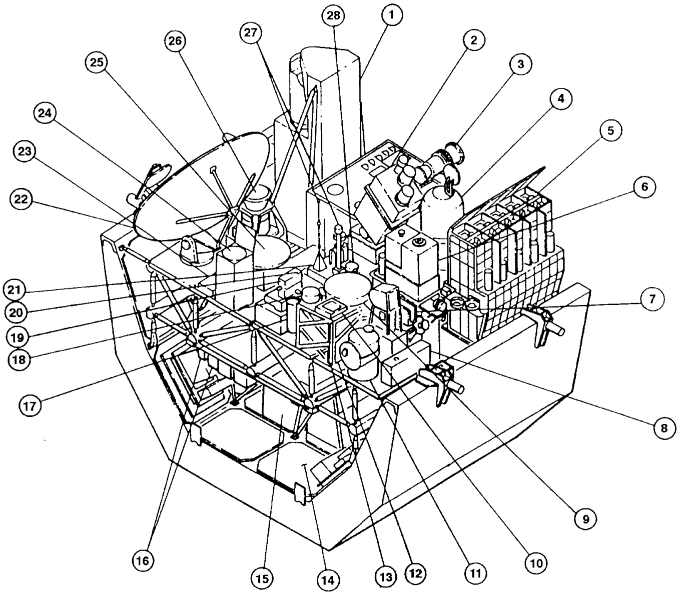


Figure 4–17. Spacelab 1 Module Experiment Locations (Starboard Side)

Spacelab 3 carried a contingent of animals living in the newly designed Research Animal Holding Facility. This facility maintained healthy, small mammals, although animal food and waste leaked from the containers because of inadequate seal design and higher than expected vigor of monkeys, who kicked the material into the airflow of their cages. During the mission, the crew members observed two monkeys and twenty-four rodents for the effects of weightlessness. The crew also served as experimental subjects, with investigations in the use of biofeedback techniques to control space sickness and in changes in body fluids brought about by weightlessness.

Atmospheric physics and chemistry experiments provided more data than previously obtained in decades of balloon-based research. An experimental atmospheric modeling machine provided more than 46,000 images useful for solar, Jupiter, and Earth studies. In all, more than 250 billion bits of data were returned during the mission, and of the fifteen experiments conducted, fourteen were considered successful.

Spacelab 2. Spacelab 2 completed the second of two planned verification flights required by the Spacelab Verification Test Flight program. Flown on STS 51-F, Spacelab 2 was a NASA-developed payload. Its configuration included an igloo attached to a lead pallet, with the instrument pointing subsystem mounted on it, a two-pallet train, and an experiment special support structure (Figure 4–20). The experiments were located on the instrument pointing subsystem, the pallets, the special support structure, and the middeck of the orbiter, and one was based on the ground.



Key:

1. Grille Spectrometer
2. Space Experiments With Particle Accelerations
3. Low Level Light Television
4. Microwave Electronics
5. Space Experiments With Particle Accelerators Monitor Television
6. Differential Radiometer
7. Faust Telescope
8. Biostack
9. Imaging Spectrometer
10. Spectrometer
11. Space Experiments With Particle Accelerators Magnetoplasma Dynamic Arcjet
12. Space Experiments With Particle Accelerators INput Unit
13. Camera/Image Intensifier
14. Space Experiments With Particle Accelerators Dedicated Experiment Processors
15. Spectrophotometer
16. Microwave Scatterometer
17. Isotopic Stack
18. Electronics Box
19. Electronics Box Assembly
20. Scintillation Counter
21. Flux Sensor
22. Active Unit
23. Space Experiments With Particle Accelerators Charger
24. Space Experiments With Particle Accelerators Electron Beam Accelerator
25. Space Experiments With Particle Accelerators
26. Space Experiments With Particle Accelerators Diagnostic Gas Plume
27. Verification Flight Instrumentation Equipment
28. Active Cavity Radiometer

Figure 4–18. Spacelab 1 Pallet Experiment Locations

The pallets provided mounting and support for experiments that required an atmosphere-free environment. The special support structure was specially designed to support the Elemental Composition and Energy Spectral of Cosmic Ray Nuclei experiment.

Fourteen experiments supported by seventeen principal investigators were conducted (Table 4–47). The experiments were in the fields of life sciences, plasma physics, infrared astronomy, high-energy physics, solar physics, atmospheric physics, and technology.

Spacelab D-1. Spacelab D-1, the “German Spacelab,” concentrated on scientific experiments on materials in a microgravity environment.

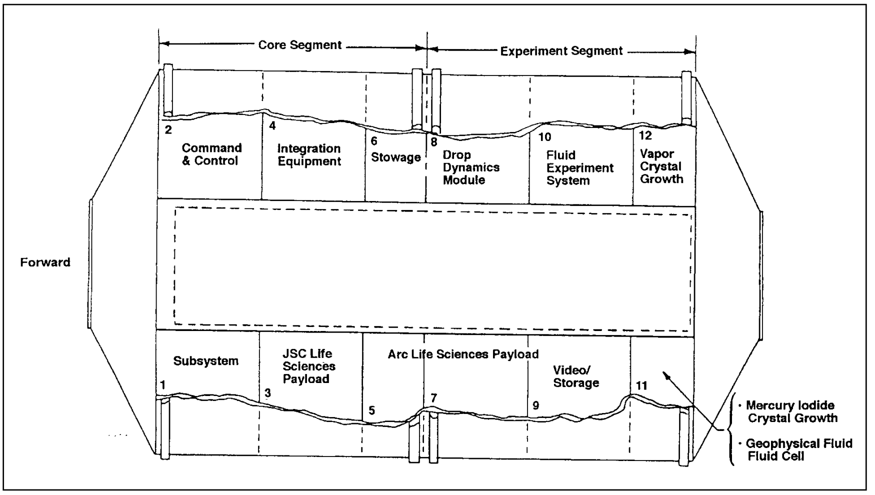


Figure 4–19. Spacelab 3 Experiment Module Layout (Looking Down From the Top)

This mission, flown on STS 61-A, was the second flight of the Materials Experiment Assembly (the first was on STS-7). Experiments included investigations of semiconductor materials, miscibility gap materials, and containerless processing of glass melts (Table 4–48).

OSS-1 (STS-3)

The OSS-1 mission objectives were to conduct scientific observations that demonstrated the Space Shuttle's research capabilities and that were

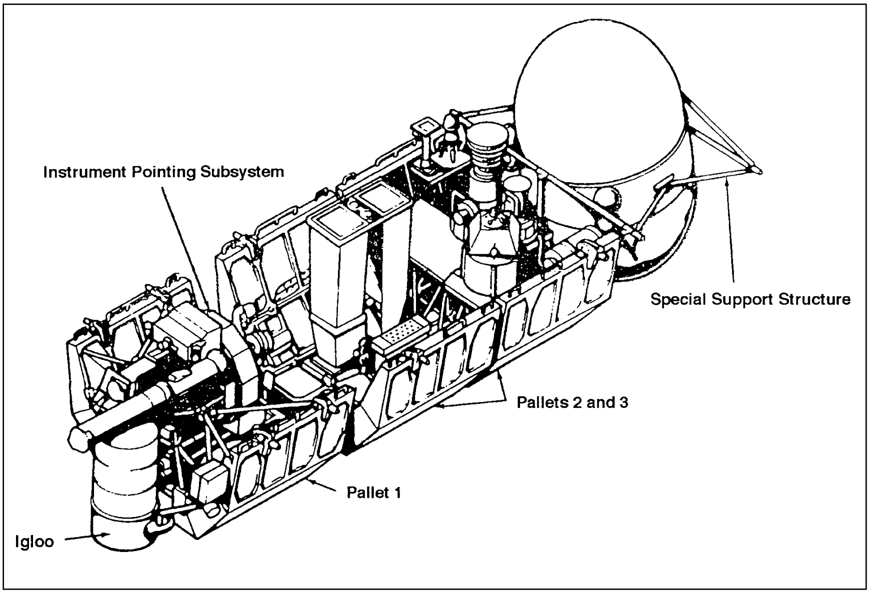


Figure 4–20. Spacelab 2 Configuration

appropriate for flight on an early mission; to conduct supplementary observations of the orbiter's environment that had specific applicability to plasma physics and astronomical payloads; and to evaluate technology that may have application in future experiments in space. The experiments obtained data on the near-Earth space environment, including the degree of contamination (gases, dust, and outgassing particles) introduced by the orbiter itself.

The OSS-1 payload, also designated the "Pathfinder Mission," was a precursor to the Spacelab missions. It was developed to characterize the environment around the orbiter associated with the operation of the Shuttle and to demonstrate the Shuttle's research capability for science applications and technology in space. It verified that research measurements could be carried out successfully on future Shuttle missions and performed scientific measurements using the Shuttle's unique capabilities.

The mission included scientific investigations in space plasma physics, solar physics, astronomy, life sciences, and space technology. Six of the nine experiments were designed by scientists at five American universities and one British university and were operated under their supervision during the mission. One experiment was developed by the Naval Research Laboratory, and two were developed by the Goddard Space Flight Center (Table 4–49). The OSS-1 experiments being flown in the orbiter's payload bay were carried on a special U-shaped structure called an orbital flight test pallet. The three-meter-by-four-meter aluminum frame and panel structure weighing 527 kilograms was a Spacelab element that would be used later in the STS program (Figure 4–21).

Other Physics and Astronomy Missions

The following sections describe physics and astronomy missions that were launched prior to 1979 and continued operating into the 1980s, followed by a discussion of missions that underwent development from 1979 to 1988 but did not launch until later. Readers can find details of the early stages of the ongoing science missions in Volume III of the *NASA Historical Data Book.*[9]

Ongoing Physics and Astronomy Missions

International Ultraviolet Explorer. The International Ultraviolet Explorer (IUE) mission was a joint enterprise of NASA, ESA, and the British Science Research Council. IUE 1, launched into geosynchronous orbit on January 26, 1978, on a Delta launch vehicle, allowed hundreds of users at two locations to conduct spectral studies of celestial ultraviolet sources. It was the first satellite totally dedicated to ultraviolet astronomy.

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[9]Ezell, *NASA Historical Data Book, Volume III.*

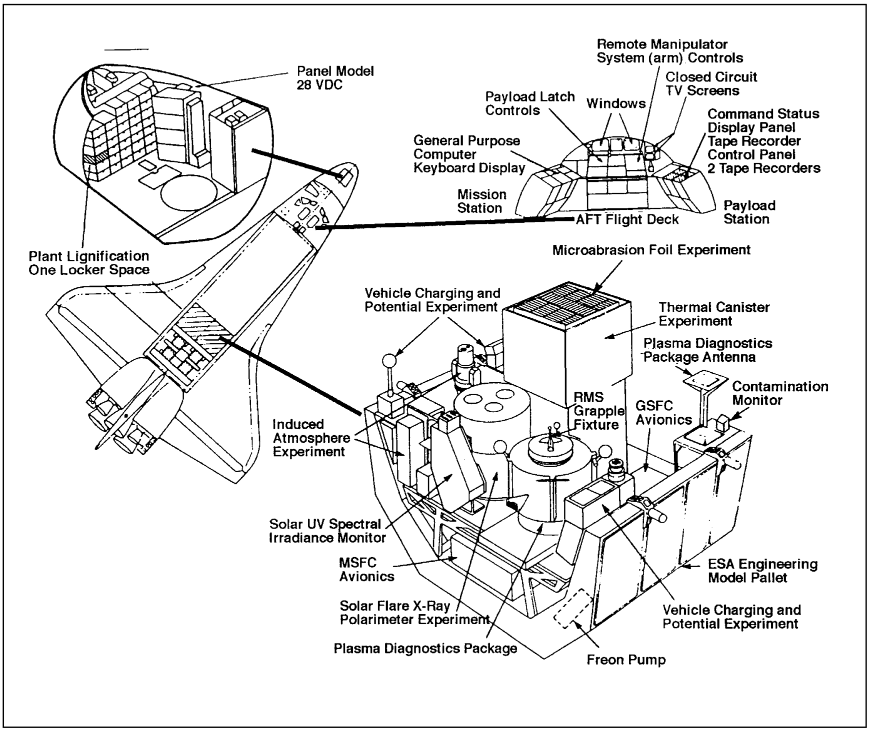

Figure 4–21. OSS-1 Payload Configuration

The IUE mission objective was to conduct spectral distribution studies of celestial ultraviolet sources. The scientific goals were to:

- Obtain high-resolution spectra of stars
- Study gas streams
- Observe faint stars, galaxies, and quasars
- Observe the spectra of planets and comets
- Make repeated observations that showed variable spectra
- Define more precisely the modifications of starlight caused by interstellar dust and gas

NASA provided the IUE spacecraft, the optical and mechanical components of the scientific instruments, the U.S. ground observatory, and the spacecraft control software. ESA contributed the solar arrays needed as a power source and the European ground observatory in Spain. The British Science Research Council oversaw the development of the spectrograph television cameras and, with the United States, the image processing software.

Targets of IUE's investigations included faint stars, hot stars, quasars, comets, gas streams, extragalactic objects, and the interstellar medium. A forty-five-centimeter Ritchey Chretien telescope aided in the investigations. Geosynchronous orbit permitted continuous observations and real-time data by the investigators at the two ground observatories. Objects observed by IUE included planets, stars, and galaxies. IUE specialized in targets of opportunity, such as comets, novae, and supernovae.

Often, IUE allowed simultaneous data acquisition and was used in conjunction with other telescopes from around the world. In its later years of operation, these collaborations involved such spacecraft as the Hubble Space Telescope, the German Roentgen Satellite, the Compton Gamma Ray Observatory, the Voyager probes, the Space Shuttle's Astro-1 mission, the Extreme Ultraviolet Explorer, and Japan's ASCA satellite, as well as numerous ground-based observatories.

In 1979, IUE produced the first evidence confirming the existence of a galactic halo, consisting of high-temperature, rarefied gas extending far above and below the Milky Way. In 1980, it verified expectations that space between isolated galaxies was highly transparent and contributed very little to the total mass of the universe. Extensive observation of active binary stars demonstrated that stellar magnetic fields and rotation probably combined to cause the tremendous levels of solar-like activity in many classes of such stellar systems. Studies using IUE data also indicated a consistent and continuous evolution of coronas, wind characteristics, and mass-loss rates, varying from the hot, fast winds and low mass-loss rate of the Sun to the slow, cool winds and high mass-loss rate of the coolest giant and supergiant stars. In addition, IUE provided the first detailed studies of comets throughout their active cycle in the inner solar system, providing new clues to their internal composition. Observations also confirmed the discovery of a hot halo of gas surrounding the Milky Way.

In 1986, IUE provided space-based observations of Halley's Comet and its tail during the Japanese, European, and Soviet missions to its nucleus and later initiated periodic observations of Supernova 1987a. The observations provided the key data required to identify the true progenitor of the supernova. As it continued to observe Supernova 1987a, IUE discovered the remnant shell from the red supergiant stage of the supernova as well as determined the changing properties of the ejecta from continuing observations. The spacecraft made the best determination of the light curve and its implications concerning the nature of the energy source.

When launched in 1978, the IUE spacecraft had a stated lifetime expectancy of three to five years. It was shut down on September 30, 1996, after more than eighteen years of mission elapsed time.

International Sun-Earth Explorer/International Cometary Explorer. The International Sun-Earth Explorer (ISEE) program was a collaborative three-spacecraft program with ESA. ISEE 3 was injected into a "halo" orbit in November 1978 about the Earth-Sun libration point, from which it observed the solar wind an hour before it reached Earth's magnetosphere. This capability could provide advance warning of impending magnetospheric and ionosphere disturbances near Earth, which the ISEE 1 and 2 spacecraft monitored. ISEE 3 also observed electrons that carried energy from Earth's bow shock toward the Sun.

Although Earth's magnetic field diverted most of the solar wind, some interacted, producing plasma waves; some transferred energy inside the magnetosphere; and some was hurled back toward the Sun.

ISEE 3 completed its original mission of monitoring the solar wind in 1983 and was maneuvered into an orbit swinging through Earth's magnetic tail and behind the Moon, using the Moon's gravity to boost the spacecraft toward rendezvous with a comet. ISEE 3 obtained the first *in situ* field and particle measurements in Earth's magnetotail. Also in 1983, NASA renamed ISEE 3 the International Cometary Explorer (ICE). It left its Earth orbit on December 22, 1983, to encounter the Comet Giacobini-Zinner on September 11, 1985. ICE passed within 8,000 kilometers of the comet's nucleus and through the comet's tail. It provided the first spacecraft data on a comet's magnetic field, plasma environment, and dust content.

Orbiting Astronomical Observatories. The Orbiting Astronomical Observatory-3, named Copernicus, continued to furnish information on an apparent black hole detected in the constellation Scorpius until its operations were shut down on December 31 1980, because of degradation in the experiment's detection system. Its work also included discoveries of clumpy structures and shocked million-degree gas in the interstellar medium and measurements of the ultraviolet spectra of the chromospheres and coronas of stars other than the Sun.

Physics and Astronomy Missions Under Development From 1979 to 1988

Hubble Space Telescope. The history of the Hubble Space Telescope can be traced back as far as 1962, when the National Academy of Sciences published a report recommending the construction of a large space telescope. In 1973, NASA established a small scientific and engineering steering committee to determine which scientific objectives would be feasible for a proposed space telescope. C. Robert O'Dell of the University of Chicago headed the team. He viewed the project as an opportunity to establish a permanent orbiting observatory. In 1978, responsibility for the design, development, and construction of the space telescope went to the Marshall Space Flight Center. The Goddard Space Flight Center was chosen to lead the development of the scientific instruments and the ground control center. Marshall selected Perkin-Elmer of Danbury, Connecticut, over Itek and Kodak to develop the optical system and guidance sensors. Lockheed Missiles and Space Company of Sunnyvale, California, was selected over Martin Marietta and Boeing to produce the protective outer shroud and the support systems module for the telescope, as well as to assemble and integrate the finished product.

ESA agreed to furnish the spacecraft solar arrays, one of the scientific instruments (Faint Object Camera), and personnel to support the Space Telescope Science Institute in exchange for 15 percent of the observing time and access to the data from the other instruments. Goddard scientists were selected to develop one instrument, and scientists at the California Institute of Technology, the University of California at San Diego, and the

University of Wisconsin were selected to develop three other instruments. The telescope's construction was completed in 1985.

Because of Hubble's complexity, NASA established two new facilities under the direction of Goddard that were dedicated exclusively to the scientific and engineering operation of the telescope. The Space Telescope Operations Control Center at Goddard would serve as the ground control facility for the telescope. The Space Telescope Science Institute, located on the campus of Johns Hopkins University, would perform the science planning for the telescope.

Hubble was originally scheduled for a 1986 launch. The destruction of *Challenger* in 1986, however, delayed the launch for several years. Engineers used the interim period to subject the telescope to intensive testing and evaluation. A series of end-to-end tests involving the Space Telescope Science Institute, Goddard, the Tracking and Data Relay Satellite System, and the spacecraft were performed during that time, resulting in overall improvements in system reliability. The launch would finally occur on April 25, 1990.

After launch, it was discovered that the telescope's primary mirror had a "spherical aberration" that caused out-of-focus images. A mirror defect only one-twenty-fifth the width of a human hair prevented Hubble from focusing all light to a single point. In addition, problems with the solar panels caused degradation in the spacecraft's pointing stability. At first many believed that that the spherical aberration, which was undetected during manufacturing because of a flawed measuring device, would cripple the telescope, but scientists quickly found a way to use computer enhancement to work around the abnormality. A repair mission aboard STS-61 in December 1993 replaced the solar panels and installed corrective lenses, which greatly improved the quality of the images. Table 4–50 outlines the development of the Hubble mission.

The scientific objectives of the Hubble mission were to investigate the composition, physical characteristics, and dynamics of celestial bodies, to examine the formation, structure, and evolution of stars and galaxies, to study the history and evolution of the universe, and to provide a long-term space-based research facility for optical astronomy. In addition, the Space Telescope Advisory Committee identified three key Hubble projects: (1) determine distances to galaxies and the Hubble Constant, (2) conduct a medium-deep survey of the sky, and (3) study quasar absorption lines.

The Hubble Space Telescope is a large Earth-orbiting astronomical telescope designed to observe the heavens from above the interference and turbulence of Earth's atmosphere. It is composed of a 2.4-meter Ritchey-Chretien reflector with a cluster of five scientific instruments at the focal plane of the telescope and the fine guidance sensors. Its scientific instruments can make observations in the ultraviolet, visible, and near-infrared parts of the spectrum (roughly 120-nanometer to one-millimeter wavelengths), and it can detect objects as faint as magnitude 31, with an angular resolution of about one-tenth arcsecond in the visible part

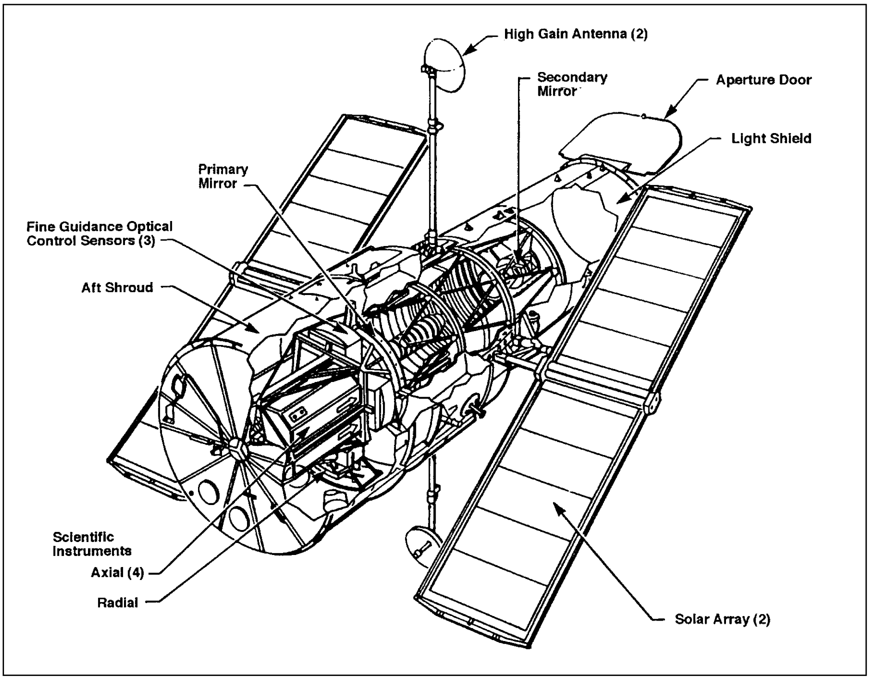

Figure 4–22. Hubble Space Telescope

of the spectrum. The spacecraft is to provide the first images of the surfaces of Pluto and its moon Charon and, by looking back in time and space, to determine how galaxies evolved in the initial period after the Big Bang. The telescope relays data to Earth via the high-gain antennae.

The Hubble Space Telescope is distinguished from ground-based observatories by its capability to observe light in the ultraviolet and near infrared. It also has an order of magnitude better resolution than is capable from within Earth's atmosphere. The telescope has a modular design, allowing on-orbit servicing via the Space Shuttle (Figure 4–22). Over the course of its anticipated fifteen-year operational lifetime, NASA plans several visits by Space Shuttle crews for the installation of new instruments, repairs, and maintenance. Hubble is about the size of a bus—it has a weight of approximately 11,000 kilograms and length of more than thirteen meters. It travels in a 611-kilometer circular orbit with an inclination of twenty-eight and a half degrees.

Compton Gamma Ray Observatory. NASA initiated the Compton Gamma Ray Observatory (CGRO) mission in 1981. It would be the second of NASA's orbiting Great Observatories, following the Hubble Space Telescope. During 1984, NASA completed the critical design reviews on all the instruments, and flight instrument hardware fabrication and assembly began. Also in 1984, NASA completed the spacecraft preliminary design review. In 1985, the design was completed, and NASA conducted the observatory critical design review. Manufacturing began on the structure and mechanisms and nearly completed fabrication of all hardware for the four scientific instruments. Manufacturing of the mechanical components and electronic systems approached completion during 1987, and the primary structure for the observatory was fabricated and assembled.

CGRO was a NASA cooperative program. The Federal Republic of Germany (the former West Germany), with co-investigator support from The Netherlands, ESA, the United Kingdom, and the United States, had principal investigator responsibility for one of the four instruments. Germany also furnished hardware elements and co-investigator support for a second instrument. NASA provided the remaining instruments and named the observatory in honor of Dr. Arthur Holly Compton, who won the Nobel Prize in physics for work on scattering of high-energy photons by electrons. This process was central to the gamma ray detection techniques of all four instruments.

CGRO was launched on April 5, 1991, aboard the Space Shuttle *Atlantis*. Dedicated to observing the high-energy universe, it would be the heaviest astrophysical payload flown to that time, weighing 15,422 kilograms, or more than fifteen metric tons (Figure 4–23). While Hubble's instruments would operate at visible and ultraviolet wavelengths, CGRO would carry a collection of four instruments that together could detect an unprecedented broad range of gamma rays. These instruments were the Burst and Transient Source Experiment, the Oriented Scintillation Spectrometer Experiment, the imaging Compton Telescope (known as COMPTEL), and the Energetic Gamma Ray Experiment Telescope.

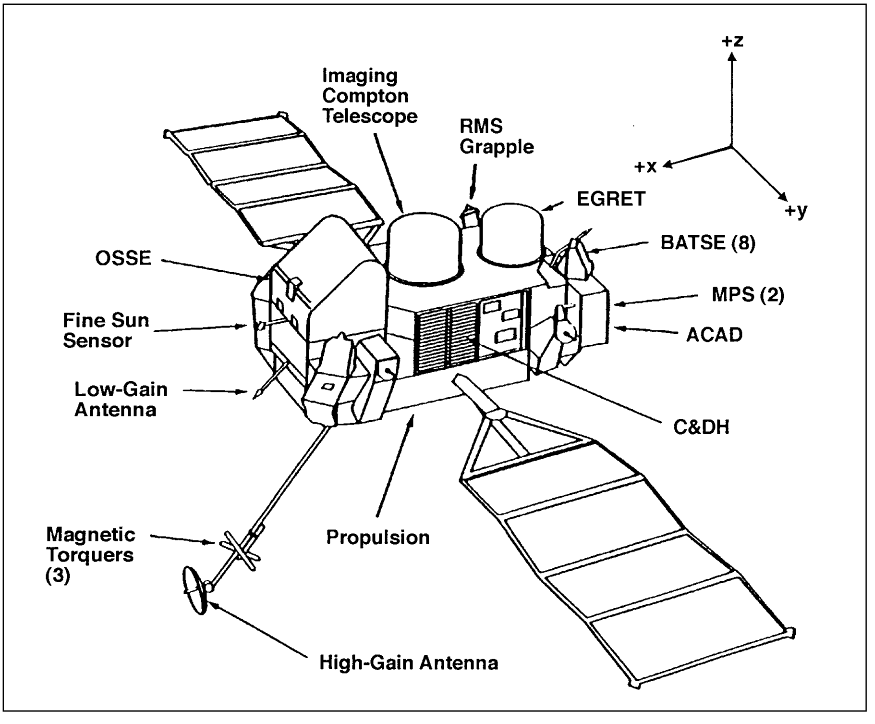

Figure 4–23. Compton Gamma Ray Observatory Configuration

These four instruments would be much larger and more sensitive than any gamma ray telescopes previously flown in space. The large size was necessary because the number of gamma ray interactions that could be recorded was directly related to the mass of the detector. Because the number of gamma ray photons from celestial sources was very small when compared to the number of optical photons, large instruments were needed to detect a significant number of gamma rays in a reasonable amount of time. The combination of these instruments would detect photon energies from 20,000 electron volts to more than 30 billion electron volts. For each of the instruments, an improvement in sensitivity of better than a factor of ten was realized over previous missions.

CGRO mission objectives were to measure gamma radiation from the universe and to explore the fundamental physical processes powering it. The observational objectives of CGRO were to search for direct evidence of the synthesis of the chemical elements, to observe high-energy astrophysical processes occurring in supernovae, neutron stars, and black holes, to locate gamma ray burst sources, to measure the diffuse gamma ray radiation for cosmological evidence of its origin, and to search for unique gamma ray emitting objects. The observatory had a diverse scientific agenda, including studies of very energetic celestial phenomena: solar flares, cosmic gamma ray bursts, pulsars, nova and supernova explosions, accreting black holes of stellar dimensions, quasar emission, and interactions of cosmic rays with the interstellar medium.

Extreme Ultraviolet Explorer. The Extreme Ultraviolet Explorer (EUVE) was an Earth-orbiting sky survey and spectroscopy mission. Its primary objectives were to produce a definitive sky map and catalogue of sources covering the extreme ultraviolet portion of the electromagnetic spectrum and to conduct pointed spectroscopy studies of selected extreme ultraviolet targets. Scientists from the University of California at Berkeley proposed the sky survey experiment for EUVE in 1975 in response to two NASA Announcements of Opportunity. NASA conditionally accepted the Berkeley concept in 1977, pending receipt of adequate funding and completion of implementation studies.

In 1981, the Jet Propulsion Laboratory assumed project management responsibilities. NASA transferred this responsibility to the Goddard Space Flight Center in 1986, following a decision to retrieve the Multimission Modular Spacecraft from the Solar Maximum Mission and refurbish it for use with EUVE. In 1986, when it became evident that the Solar Maximum Mission would reenter Earth’s atmosphere before a retrieval mission could be mounted, NASA exercised its option to procure a new spacecraft from Fairchild Space. The resulting Explorer Platform was an upgraded version of the Multimission Modular Spacecraft. Initially, this spacecraft bus would have a dual-launch capability—that is, it could use both Shuttle and Delta launch vehicles. In 1988, NASA decided to launch EUVE on a Delta. Figure 4–24 shows the major elements of the EUVE observatory.

EUVE would conduct the first detailed all-sky survey of extreme ultraviolet radiation between 100 and 900 angstroms, a previously unex-

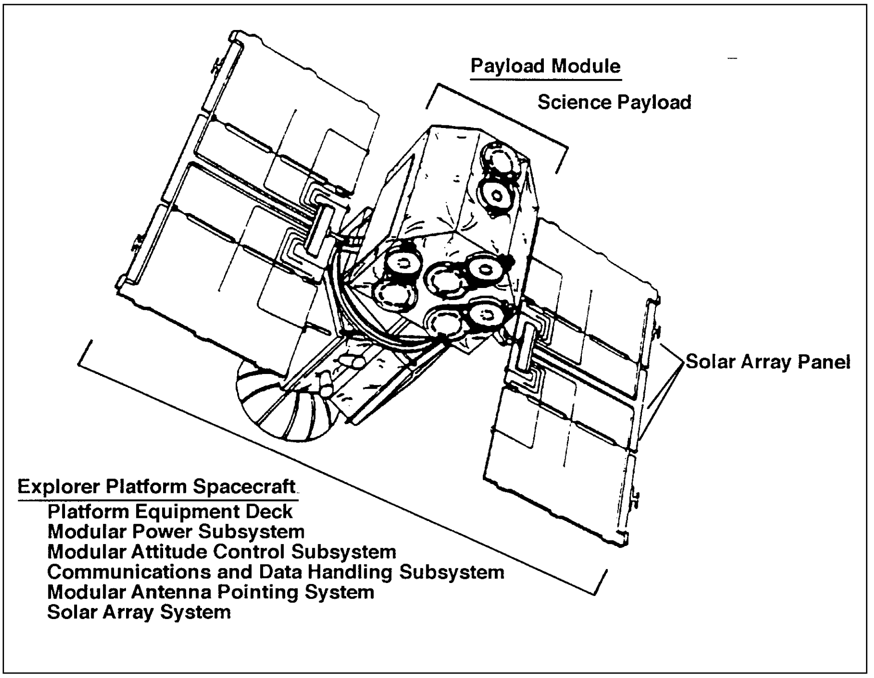

Figure 4–24. Extreme Ultraviolet Explorer Observatory

plored portion of the electromagnetic spectrum. EUVE would be a two-phase mission, with the first six months devoted to scanning the sky to locate and map sources emitting radiation in the extreme ultraviolet range and the remainder of the mission (about twenty-four months) devoted to detailed spectroscopy of sources located during the first phase (Figure 4–25). NASA launched EUVE on a Delta launch vehicle in June 1992. Upon completion of the EUVE mission, plans were to have the Shuttle rendezvous with the Explorer Platform and replace the EUVE payload with the X-ray Timing Explorer (XTE), which would monitor changes in the x-ray luminosity of black holes, quasars, and x-ray pulsars and would investigate physical processes under extreme conditions.[10]

Roentgen Satellite. The Roentgen Satellite (ROSAT) was a cooperative project of the West Germany, the United Kingdom, and the United States to perform high-resolution imaging studies of the x-ray sky. The mission's objectives were to study coronal x-ray emissions from stars of all spectral types, to detect and map x-ray emissions from galactic supernova remnants, to evaluate the overall spatial and source count distributions for various x-ray sources, to perform a detailed study of various populations of active galaxy sources, to perform a morphological study of the x-ray emitting clusters of galaxies, and to

[10]The Shuttle was not used to launch the X-ray Timing Explorer, which was launched on a Delta rocket in December 1995.

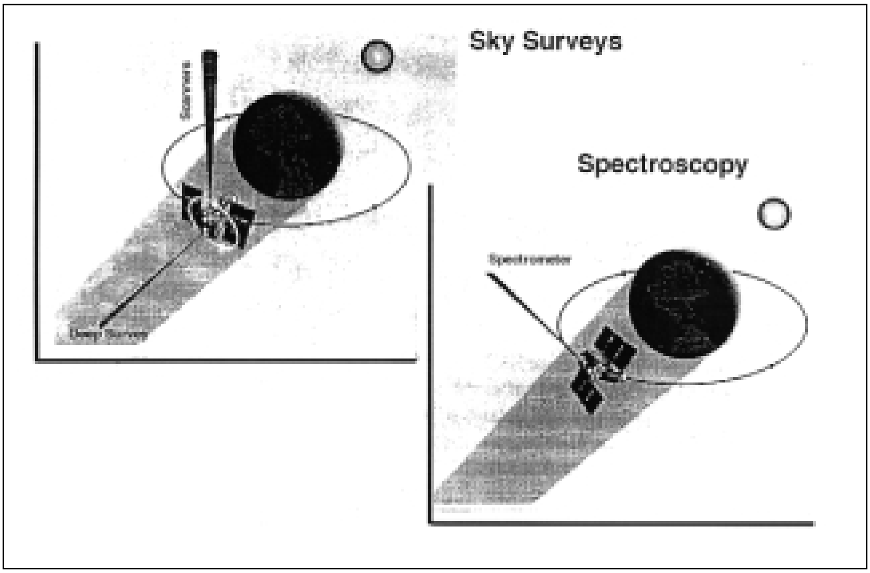

Figure 4–25. Two Phases of the Extreme Ultraviolet Explorer Mission

perform detailed mapping of the local interstellar medium by the extreme ultraviolet survey.

The United States would provide a high-resolution imaging instrument and launch services. West Germany would contribute the spacecraft and the main telescope, and the United Kingdom would provide the wide-field camera. The ROSAT project originated from a 1975 proposal to the Bundeministerium für Forschungs und Technologie (BMFT) from scientists at the Max Planck Institut fuer Extraterrestrische Physik (MPE). The original objective was to conduct an all-sky survey with an imaging x-ray telescope of moderate angular resolution. Between 1977 and 1982, German space companies carried out extensive advance studies and preliminary analyses. Simultaneously, the Carl Zeiss Company in Germany initiated the development of a large x-ray mirror system, and MPE began to develop the focal plane instrumentation.

In 1979, following the regulations of ESA convention, BMFT announced the opportunity for ESA member states to participate by offering the possibility of flying a small, autonomous experiment together with the large x-ray telescope. In response to this announcement, a consortium of United Kingdom institutes led by Leicester University proposed an extreme ultraviolet wide-field camera to extend the spectral band measured by the x-ray telescope to longer wavelengths. The British Science and Engineering Research Council approved this experiment, and in 1983, BMFT and the council signed an MOU.

In 1981 and 1982, NASA and BMFT conducted negotiations for U.S. participation in the ROSAT mission, with the resulting MOU signed in 1982. Under this MOU, NASA agreed to provide the ROSAT launch with the Space Shuttle and a focal-point high-resolution imager detector.

BMFT's responsibilities included the design, fabrication, test, and integration of the spacecraft; mission control, tracking, and data acquisition after separation from the Shuttle; and the initial reduction and distribution of data. NASA would provide, at minimal charge, a flight model copy of the high-resolution imager previously flown on the 1978 High Energy Astronomy Observatories mission (HEAO-2). In 1983, NASA Headquarters issued a sole-source contract to the Smithsonian Astrophysical Observatory to build flight and engineering model high-resolution imagers and provide integration and launch support. In May 1985, NASA transferred this contract to the Goddard Space Flight Center for administration and implementation.

The *Challenger* accident led to a reconsideration of schedules and the launch vehicle. In 1987, NASA and BMFT decided to launch with a Delta launch vehicle. Germany redesigned the spacecraft appropriately, and the United States developed a new three-meter fairing for the Delta II nose section to accommodate ROSAT's maximum cross-sectional dimension. ROSAT was launched on a Delta rocket in June 1990. Figure 4–26 shows the ROSAT flight configuration.

Cosmic Background Explorer. The development of the Cosmic Background Explorer (COBE) began during fiscal year 1982. Developed by NASA's Goddard Space Flight Center, COBE would measure the diffuse infrared and microwave radiation from the early universe, to the limits set by our astrophysical environment. The spacecraft would carry out a definitive, all-sky exploration of the infrared background radiation of the universe between the wavelengths of one micrometer and 9.6 millimeters. The detailed information that COBE was to provide on the spectral and

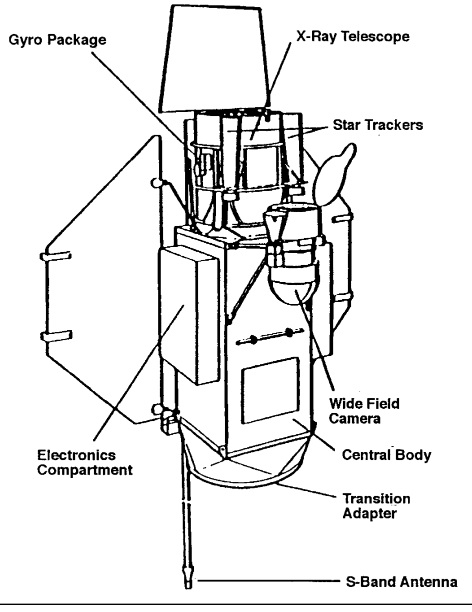

Figure 4–26. ROSAT Flight Configuration

spatial distribution of low-energy background radiation was expected to yield significant insight into the basic cosmological questions of the origin and evolution of the universe. COBE would measure the residual three-Kelvin background radiation believed to be a remnant of the "Big Bang" origin of the universe.

COBE, as initially proposed, was to have been launched by a Delta rocket. However, once the design was under way, the Shuttle was adopted as the NASA standard launch vehicle. After the *Challenger* accident occurred in 1986, ending plans for Shuttle launches from the west coast, NASA redesigned the spacecraft to fit within the weight and size constraints of the Delta. Three of the subsystems that on the Shuttle would have been launched as fixed components—the solar arrays, radio-frequency/thermal shield, and antenna—had to be replaced by deployable systems. The final COBE satellite had a total mass of 2,270 kilograms, a length of 5.49 meters, and a diameter of 2.44 meters with Sun-Earth shield and solar panels folded (8.53 meters with the solar panels deployed) rather than the 4,990 kilograms in weight and 4.3 meters in diameter allowed with a Shuttle launch. (Figure 4–27 shows the COBE observatory.) In 1988, instrument development was completed, the flight hardware delivered, and the observatory integration completed.

COBE was launched aboard a Delta rocket on November 18, 1989, from the Western Space and Missile Center at Vandenberg Air Force Base, California, into a Sun-synchronous orbit. Its orbital alignments are shown in Figure 4–28. COBE carried three instruments: a far-infrared absolute spectrophotometer to compare the spectrum of the cosmic microwave background radiation with a precise blackbody, a differential microwave radiometer to map the cosmic radiation precisely, and a diffuse infrared background experiment to search for the cosmic infrared background radiation. COBE has transmitted impressive data that strongly supports the Big Bang theory of the origin of the universe.

Planetary Exploration Program

NASA launched no new planetary exploration missions from 1979 to 1988. However, missions that had been launched earlier continued returning outstanding data to scientists on the ground. Details of the early years of these missions can be found in Volume III of the *NASA Historical Data Book.*[11] NASA also continued preparing for missions that had originally been scheduled for launch during this decade but were delayed by the *Challenger* accident.

The Planetary Exploration program encompassed the scientific exploration of the solar system, including the planets and their satellites, comets and asteroids, and the interplanetary medium. The program objectives were to:

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[11]Ezell, *NASA Historical Data Book, Volume III.*

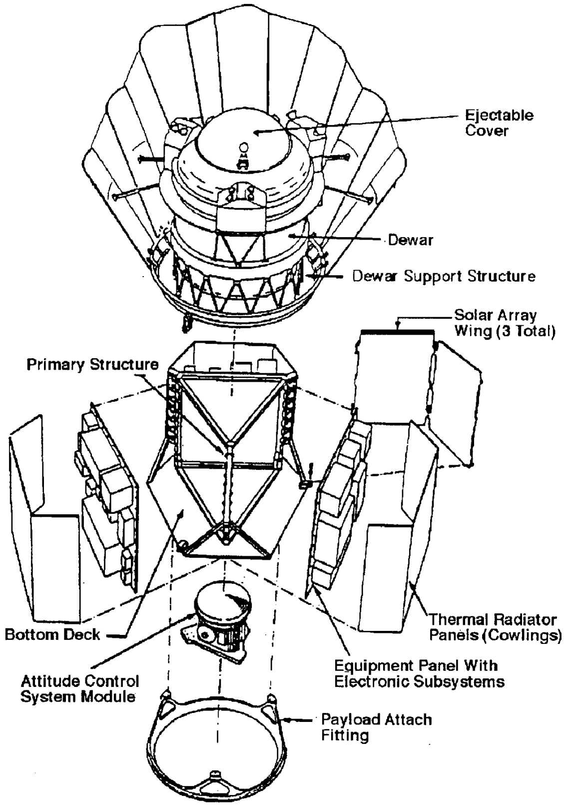

Figure 4–27. Cosmic Background Explorer Observatory (Exploded View)

- Determine the nature of planets, comets, and asteroids as a means for understanding the origin and evolution of the solar system
- Understand Earth better through comparative studies with the other planets
- Understand how the appearance of life in the solar system was related to the chemical history of the solar system
- Provide a scientific basis for the future use of resources available in near-Earth space

NASA's strategy emphasized equally the Earth-like inner planets, the giant gaseous outer planets, and the small bodies (comets and asteroids). Missions to these planetary bodies began with reconnaissance and exploration to achieve the most fundamental characterization of the bodies and proceeded to detailed study. In general, the reconnaissance phase of inner planet exploration began in the 1960s and was completed by the late 1970s. Most activities that occurred in the 1980s involved more detailed study of the inner planetary bodies or the early stages of study about the outer planets and small bodies.

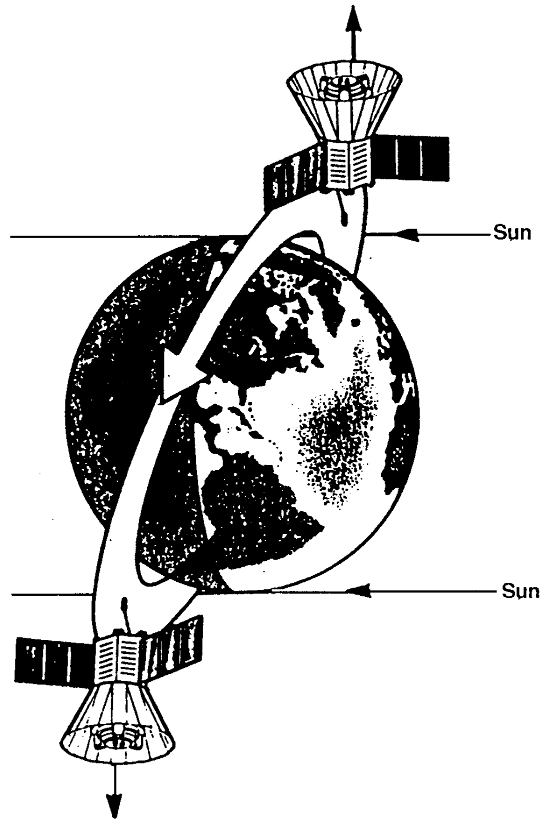

Figure 4–28. Cosmic Background Explorer Orbital Alignments

Voyager Program

The objectives of the Voyager missions were to conduct comparative studies of the Jupiter and Saturn planetary systems, including the satellites and Saturn's rings, and to study the interplanetary medium between Earth and Saturn. Voyager 1 encountered both planets, using Jupiter's gravity to go on to Saturn in 1980, scanned Saturn's primary moon Titan, and was flung by Saturn's gravity up out of the ecliptic plane. Voyager 2 followed Voyager 1 to Jupiter and Saturn, and it then proceeded to Uranus and Neptune, using the gravity of each previous planet to go on to the next one. This outer planet "grand tour" required a planetary alignment that repeats only once every 176 years.[12]

NASA launched Voyager 1 on September 5, 1977. It began its measurements of the Jovian system on January 6, 1979, with its closest

[12]"Handy Facts," *The Voyager Neptune Travel Guide,* NASA Jet Propulsion Laboratory, JPL Publication 89-24, June 1, 1989.

approach occurring on March 5, 1979, when it reached within 277,400 kilometers of the surface. During that year, the spacecraft returned more than 18,000 images of Jupiter and its four Galilean planets and mapped the accessible portion of Jupiter's complex magnetosphere.

Voyager discovered the presence of active volcanoes on the Galilean moon Io. Volcanic eruptions had never before been observed on a world other than Earth. The Voyager cameras identified at least nine active volcanoes on Io, with plumes of ejected material extending as far as 280 kilometers above the moon's surface. Io's orange and yellow terrain probably resulted from the sulfur-rich materials brought to the surface by volcanic activity that resulted from tidal flexing caused by the gravitational pull among Io, Jupiter, and the other three Galilean moons.

The spacecraft encountered Saturn in November 1980, approaching within 123,910 kilometers of the surface. Voyager 1 found hundreds, and perhaps thousands, of elliptical rings and one that appeared to be seven twisted or braided ringlets. It passed close to its ring system and to Titan, and it also provided a first close-up view of several of its other moons. Voyager 1 determined that Titan had a nitrogen-based atmosphere with methane and argon—one more similar to Earth's in composition than the carbon dioxide atmosphere of Mars and Venus. Titan's surface temperature of –179 degrees Celsius implied that there might be water-ice islands rising above oceans of ethane-methane liquid or sludge. However, Voyager 1's cameras could not penetrate the moon's dense clouds. Following this encounter, the satellite began to travel out of the solar system as its instruments studied the interplanetary environment.

A Titan-Centaur launched Voyager 2 on August 20, 1977. Its closest approach to Jupiter occurred on July 9, 1979, when it reached 277,400 kilometers from Jupiter's surface. The spacecraft provided patterns of Jupiter's atmosphere and high-resolution views of volcanoes erupting on Io and views of other Galilean satellites and clear pictures of Jupiter's ring.

Voyager 2 came closest to Saturn on August 25, 1981, approaching 100,830 kilometers, and returned thousands of high-resolution images and extensive data. It obtained new data on the planets, satellites, and rings, which revolutionized concepts about the formation and evolution of the solar system. Additional scientific detail on the planet returned by the spacecraft suggested that the rings around Saturn were alternating bands of material at increased and decreased densities. Saturn's eighteenth moon was discovered in 1990 from images taken by Voyager 2 in 1981.

Leaving Saturn's neighborhood, the spacecraft continued on its trip and approached Uranus on January 24, 1986, at a distance of 81,440 kilometers. It was the first spacecraft to look at this giant outer planet. From Uranus, Voyager 2 transmitted planetary data and more than 7,000 images of the planet, its rings, and moons. Voyager 2 discovered ten new moons, twenty new rings, and an unusual magnetic field around the planet. Voyager 2 discovered that Uranus's magnetic field did not follow the usual north-south axis found on the other planets. Instead, the field was tilted sixty degrees and offset from the planet's center. Uranus's atmosphere consisted mainly of hydrogen, with approximately 12 percent helium and small amounts of ammonia, methane, and water vapor. The planet's blue color occurred because the methane in its atmosphere absorbed all other colors.

On its way from Uranus to Neptune, Voyager 2 continued providing data on the interplanetary medium. In 1987, Voyager 2 observed Supernova 1987A and continued intensive stellar ultraviolet astronomy in 1988. Toward the end of 1988, Voyager 2 returned its first color images of Neptune. Its closest approach to Neptune occurred on August 25, 1989, approaching within 4,850 kilometers. The spacecraft then flew to the moon Triton. During the Neptune encounter, it became clear that the planet's atmosphere was more active than that of Uranus. Voyager 2 also provided data on Neptune's rings. Observations from Earth indicated that there were arcs of material in orbit around the planet. It was not clear from Earth how Neptune could have arcs and how these could be kept from spreading out into even, unclumped rings. Voyager 2 detected these arcs, but discovered that they were, in fact, part of thin, complete rings. Leaving Neptune's environment, Voyager 2 continued its journey away from the Sun.

Viking Program

The objective of Vikings 1 and 2 were to observe Mars from orbit and direct measurements in the atmosphere and on the surface, with emphasis on biological, chemical, and environmental data relevant to the existence of life on the planet. NASA had originally scheduled Viking 1 for an equatorial region and Viking 2 for the middle latitudes. NASA launched Viking 1 on August 20, 1975, and followed with the launch of Viking 2 on September 9. Their landings on Mars in the summer of 1976 set the stage for the next step of detailed study of the planet, the Mars Observer mission, which NASA approved in 1984.

The Viking orbiters and landers exceeded their design lifetime of 120 and ninety days, respectively. Viking Orbiter 2 was the first to fail on July 24, 1978, when a leak depleted its attitude-control gas. Viking Lander 2 operated until April 12, 1980, when it was shut down because of battery degeneration. Viking Orbiter 1 quit on August 7, 1980, when the last of its attitude-control gas was used up. Viking Lander 1 ceased functioning on November 13, 1983.

Pioneer Program

Pioneers 10 and 11. NASA launched Pioneers 10 and 11 in the 1972 and 1983, respectively, and the spacecraft continued to return data throughout the 1980s. Their objectives were to study interplanetary characteristics (asteroid/meteoroid flux and velocities, solar plasma, magnetic fields, and cosmic rays) beyond two astronomical units and to determine characteristics of Jupiter (magnetic fields, atmosphere, radiation balance, temperature distribution, and photopolarization). Pioneer 11 had the additional objective of traveling to Saturn and making detailed observations of the planet and its rings.

The flybys of Jupiter by Pioneers 10 and 11 returned excellent data, which contributed significantly to the success of the 1979 flybys of two Voyager spacecraft through the Jovian system. The spacecraft made numerous discoveries as a result of these encounters, and they demonstrated that a safe, close passage by Saturn's rings was possible. The first close-up examination of Saturn occurred in September 1979, when Pioneer 11 reached within 21,400 kilometers of that planet after receiving a gravity-assist at Jupiter five years earlier.

During 1979, Pioneer 10 traveled 410 million kilometers on its way out of the solar system and continued to return basic information about charged particles and electromagnetic fields of interplanetary space where the Sun's influence was fading. It crossed Uranus's orbit in July 1979 on its trip out of the solar system. The spacecraft crossed Neptune's orbit in May 1983, and on June 13, 1983, it became the first artificial object to leave the solar system, heading for the star Aldebaran of the constellation Taurus. During 1985, it returned data on the interstellar medium at a distance of nearly thirty-five astronomical units from the Sun. This was well beyond the orbit of Neptune and in the direction opposite to the solar apex, which is the direction of the Sun's motion with respect to nearby stars. Through 1985 and 1986, it continued to return data, aiming to detect the heliopause, the boundary between the Sun's magnetic influence and interstellar space, and to measure the properties of the interplanetary medium well outside the outer boundary of the solar system.

Pioneer 11, launched in 1973, headed in the opposite direction and completed the first spacecraft journey to Saturn in September 1979. It discovered that the planet radiates more heat than it received from the Sun and also discovered Saturn's eleventh moon, a magnetic field, and two new rings. The spacecraft continued to operate and return data as it moved outward from the Sun during the next several years. By 1987, Pioneer 11 was approaching the orbit of Neptune.

Pioneer Venus. In 1978, NASA launched two Pioneer probes to Venus. Their objectives were to jointly conduct a comprehensive investigation of the atmosphere of Venus. Pioneer Venus 1 would determine the composition of the upper atmosphere and ionosphere, observe the interaction of the solar wind with the ionosphere, and measure the planet's gravitational field. Pioneer Venus 2 would conduct its investigations with hard-impact probes—one large probe, three small probes, and the spacecraft bus would take in situ measurements of the atmosphere on their way to the surface to determine the nature and composition of clouds, the composition and structure of the atmosphere, and the general circulation patterns of the atmosphere.

Pioneer Venus 1 went into orbit around Venus in late 1978 and completed its primary mission in August 1979. A radio altimeter provided the first means of seeing through the planet's dense cloud cover and determining surface features over almost the entire planet. It also observed the comets and obtained unique images of Halley's Comet in 1986, when the comet was behind the Sun and unobservable from Earth. The spacecraft also measured the solar wind interaction, which was found to be comet-like.

Pioneer Venus 2 released its payload of hard-landers in November 1978. These probes were designated for separate landing zones so that investigators could take on-site readings from several areas of the planet during a single mission.

The Pioneer Venus mission carried the study of the planet beyond the reconnaissance stage to the point where scientists were able to make a basic characterization of the massive cloud-covered atmosphere of Venus, which contained large concentrations of sulfur compounds in the lower atmosphere. This characterization also provided some fundamental data about the formation of the planet. However, because of the opacity of the atmosphere, information about the Venus surface character remained sparse. Therefore, in 1981, NASA proposed the Venus Orbiting Imaging Radar mission, which would use a synthetic aperture radar instrument on a spacecraft in low circular orbit to map at least 70 percent of the surface of Venus at a resolution better than about 400 meters. The radar sensor was also to collect radio emission and altimetry data over the imaged portions of Venus's surface. However, the Venus Orbiting Imaging Radar mission was canceled in 1982.

Magellan

In 1983, NASA replaced the Venus Orbiting Imaging Radar mission with a more focused, simpler mission, provisionally named the Venus Radar Mapper. Nonradar experiments were removed from the projected payload, but the basic science objectives of the Venus Orbiting Imaging Radar mission—investigation of the geological history of the surface and the geophysical state of the interior of Venus—were retained. NASA selected Hughes Aircraft Company as the prime contractor for the radar system, Martin Marietta Astronautics Group had responsibility for the spacecraft, and the Jet Propulsion Laboratory managed the mission. In 1986, NASA renamed the mission Magellan in honor of Ferdinand Magellan.

The objective of the Magellan mission was to address fundamental questions regarding the origin and evolution of Venus through global radar imagery of the planet. Magellan was also to obtain altimetry and gravity data to accurately determine Venus's topography and gravity field, as well as internal stresses and density variations. The detailed surface morphology of Venus was to be analyzed to compare the evolutionary history of Venus with that of Earth. The spacecraft configuration is shown in Figure 4–29.

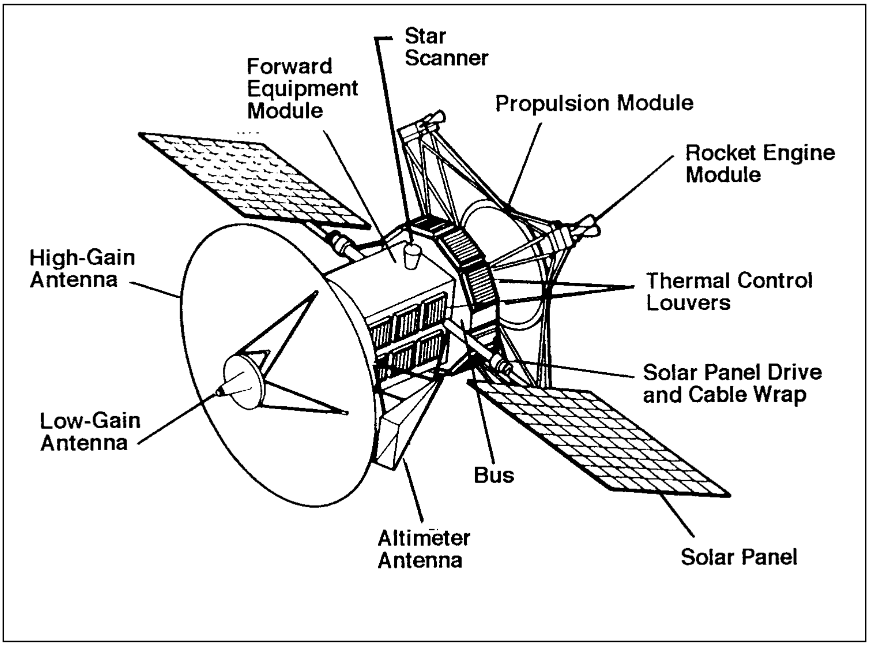

Figure 4–29. Magellan Spacecraft Configuration

Originally scheduled for a 1988 launch, NASA remanifested Magellan after the *Challenger* accident and the elimination of the Centaur upper stage. The launch took place on May 4, 1989, on STS-30, with an inertial upper stage boosting the spacecraft into a Venus transfer orbit (Figure 4–30). Magellan would reveal a landscape dominated by volcanic features, faults, and impact craters. Huge areas of the surface would show evidence of multiple periods of lava flooding with flows lying on top of previous ones. The Magellan mission would end on October 12, 1994, when the spacecraft was commanded to drop lower into the fringes of the Venusian atmosphere during an aerodynamic experiment, and it burned up, as expected. Magellan would map 98 percent of the planet's surface with radar and compile a high-resolution gravity map of 95 percent of the planet.

Project Galileo

Project Galileo had its genesis during the mid-1970s. Space scientists and NASA mission planners at that time were considering the next steps in outer planet exploration. Choosing Jupiter, which was the most readily accessible of the giant planets, as the next target, they realized that an advanced mission should incorporate a probe to descend into the atmosphere and a relatively long-lived orbiter to study the planet, its satellites, and the Jovian magnetosphere. NASA released the Announcement of Opportunity in 1976. The science payload was tentatively selected in August 1977 and confirmed in January 1979. Congress approved the Jupiter orbiter-probe mission in 1977. The program was renamed Project

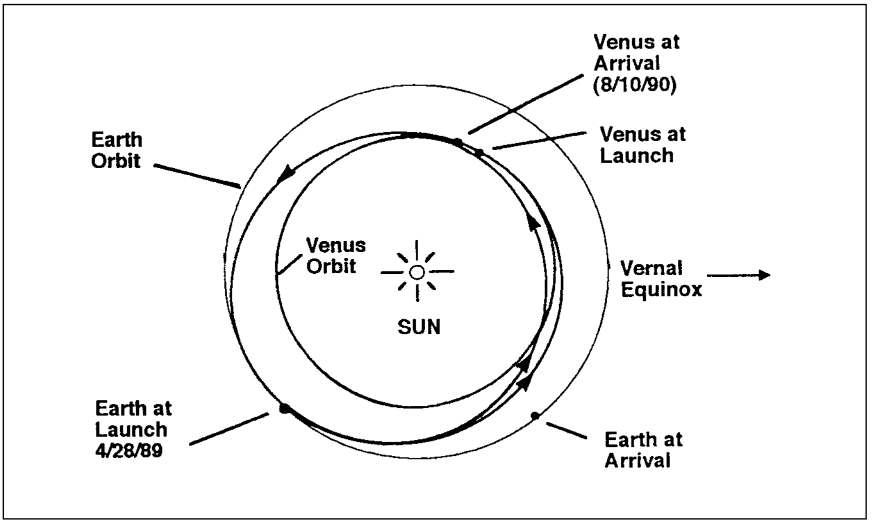

Figure 4–30. Magellan Orbit

Galileo in honor of the Italian astronomer who discovered the four large satellites of Jupiter.

Project Galileo was a cooperative effort between the United States and the Federal Republic of Germany (West Germany). A wide range of science experiments, chosen to make maximum progress beyond the Voyager finds, was selected. The mission was originally planned for an early 1985 launch on a Shuttle/Centaur upper stage combination but was delayed first to 1986 and then to 1989 because of the *Challenger* accident and the cancellation of the Centaur upper stage. Planned to operate for approximately twenty months, the Galileo spacecraft was launched October 18, 1989, on STS-34, assisted by an inertial upper stage on a trajectory using gravity assists at Venus and Earth. The orbiter would be able to make as many as ten close encounters with the Galilean satellites.

Project Galileo would send a sophisticated, two-part spacecraft to Jupiter to observe the planet, its satellites, and its space environment. The objective of the mission was to conduct a comprehensive exploration of Jupiter and its atmosphere, magnetosphere, and satellites through the use of both remote sensing by an orbiter and in situ measurements by an atmospheric probe. The scientific objectives of the mission were based on recommendations by the National Academy of Sciences to provide continuity, balance, and orderly progression of the exploration of the solar system.

Galileo would make three planetary gravity-assist swingbys (one at Venus and two at Earth) needed to carry it out to Jupiter in December 1995. (Figure 4–31 shows the Galileo trajectories.) There, the spacecraft would be the first to make direct measurements from a heavily instrumented probe within Jupiter's atmosphere and the first to conduct long-term observations of the planet, its magnetosphere, and its satellites from orbit.

The Galileo spacecraft would have three segments to investigate the planet's atmosphere, the satellites, and the magnetosphere. The probe

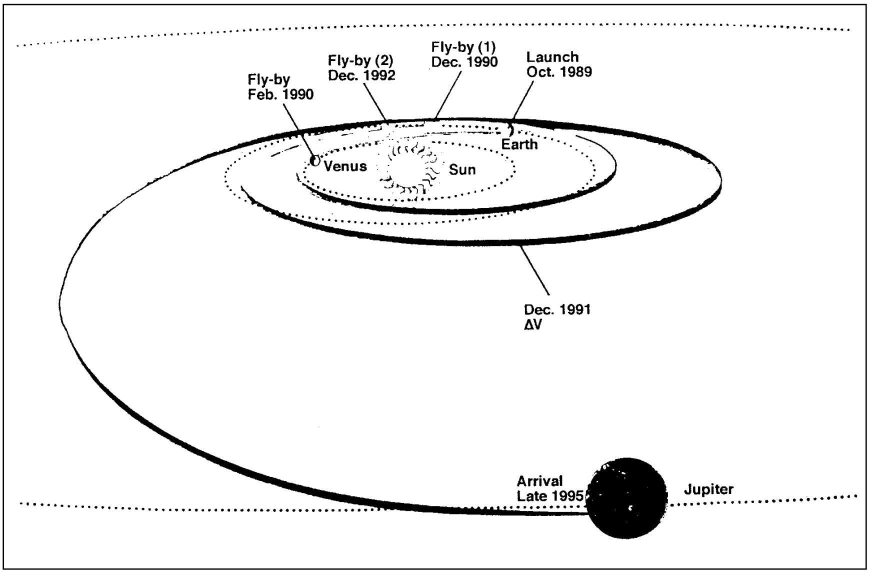

Figure 4–31. Galileo Mission

would descend into the Jovian atmosphere; a nonspinning section of the orbiter carrying cameras and other aimed sensors would image the planet and its satellites; and the spinning main orbiter spacecraft that carried fixed instruments would sense and measure the environment directly as the spacecraft flew through it (Figure 4–32). Unfortunately, after launch, the high-gain antenna on the probe would fail, reducing the amount of data that could be transmitted. Even so, the Galileo orbiter continued to transmit data from the probe throughout 1996.

Ulysses

The International Solar Polar Mission (renamed Ulysses in 1984) was a joint mission of NASA and ESA, which provided the spacecraft and some scientific instrumentation. NASA provided the remaining scientific instrumentation, the launch vehicle and support, tracking support, and the radioisotope thermoelectric generator. The mission was designed to obtain the first view of the Sun above and below the plane in which the planets orbit the Sun. The mission would study the relationship between the Sun and its magnetic field and particle emissions (solar wind and cosmic rays) as a function of solar latitude to provide a better understanding of solar activity on Earth's weather and climate. Figure 4–33 shows the spacecraft configuration.

The basis for the Ulysses project was conceived in the late 1950s by J.A. Simpson, a professor at the University of Chicago. Initially planned as a two-spacecraft mission between NASA and ESA, this mission, called "Out of Ecliptic," would allow scientists to study regions of the Sun and the surrounding space environment above the plane of the ecliptic that had never before been studied. Later, the project name was changed to the

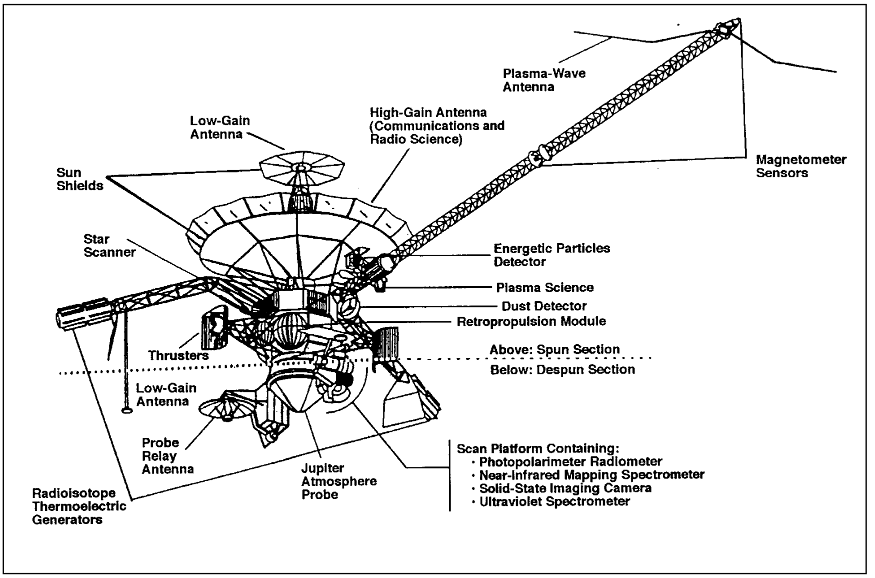

Figure 4–32. Galileo Spacecraft

International Solar Polar Mission. Delays in Shuttle development and concerns over the effectiveness of the inertial upper stage led to a House Appropriations Committee recommendation in the 1980 Supplemental Appropriations Bill that the International Solar Polar Mission be terminated. Later, in 1981, budget cuts led NASA to cancel the U.S. spacecraft contribution to the joint mission, which was restructured to a single ESA spacecraft mission. This was the first time that NASA had reneged on an international commitment. The ESA spacecraft completed its flight acceptance tests in early 1983 and was placed in storage.

In 1984, the International Solar Polar Mission was renamed Ulysses. It was originally scheduled to launch in 1986 but was another victim of the *Challenger* accident and the elimination of the Centaur upper stage. The launch took place in October 1990 using the Shuttle and both an inertial upper stage and payload assist module upper stage. The launch services were contributed by NASA. Table 4–51 presents an overview of the history of the Ulysses project.

Mars Geochemical-Climatology Orbiter/Mars Observer

The Mars Observer mission was the first in a series of planetary observer missions that used a lower cost approach to inner solar system exploration. This approach starts with a well-defined and focused set of science objectives and uses modified production-line Earth-orbital spacecraft and instruments with previous spaceflight heritage. The objectives of the Mars Observer mission were to extend and complement the data

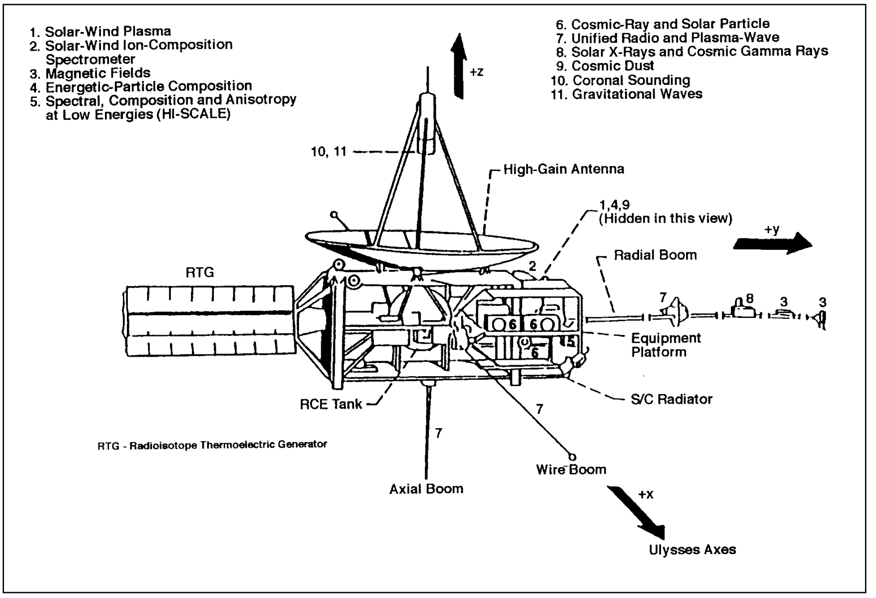

Figure 4–33. Ulysses Spacecraft Configuration

acquired by the Mariner and Viking missions by mapping the global surface composition, atmospheric structure and circulation, topography, figure, gravity, and magnetic fields of Mars to determine the location of volatile reservoirs and observe their interaction with the Martian environment over all four seasons of the Martian year.

The Mars Observer was launched on September 25, 1992. It lost contact with Earth on April 21, 1993, three days before it was to enter orbit around Mars.

Small Planetary Bodies

In 1985, NASA made the first close-up studies of the solar system's comets and asteroids. These objects may represent unaltered original solar system material preserved from the geological and chemical changes that took place in even smaller planetary bodies. By sampling and studying comets and asteroids, scientists could begin to inquire into the origin of the solar system itself. These efforts began with the encounter of Comet Giacobini-Zinner by the International Cometary Explorer spacecraft in September 1985 and continued with the 1986 encounters of Comet Halley by U.S. and foreign spacecraft and by intensive studies of the comet from ground-based observatories coordinated through the International Halley Watch.

Table 4–1. Total Space Science Funding History (in thousands of dollars)

Year and Budget Item	Request	Authorization	Appropriation	Programmed (Actual)
1979 - Space Science	**513,200**	**515,200**	—	**505,400**
Physics and Astronomy	285,500	285,500	*a*	282,900
Lunar and Planetary	187,100	187,100	*b*	182,400
Life Sciences	40,600	42,600	*c*	40,100
1980 - Space Science	**601,600**	**601,600**		**600,500**
Physics and Astronomy	337,500	337,500	*d*	336,800
Planetary Exploration	220,200	220,200	*e*	219,900
Life Sciences	43,900	43,900	*f*	43,800
1981 - Space Science	**561,000**	**577,500**	**541,488** *g*	**541,488**
Physics and Astronomy	346,600 *h*	352,700	323,700 *i*	323,700
Planetary Exploration	175,300 *j*	179,600	175,600 *k*	175,600
Life Sciences	39,100 *l*	45,200	42,188 *m*	42,188
1982 - Space Science	**584,200**	**592,200**	—	**588,133**
Physics and Astronomy	325,400 *n*	333,400	*o*	322,433
Planetary Exploration	215,300 *p*	215,300	*q*	210,000
Life Sciences	43,500 *r*	43,500	43,500 *s*	39,500
1983 - Space Science	**682,000**	**707,000**	**697,800**	**712,400**
Physics and Astronomy	471,700	473,700	461,700 *t*	470,300
Planetary Exploration	154,600	177,600	180,400 *u*	186,400
Life Sciences	55,700	55,700	55,700	55,700
1984 - Space Science	**779,000**	**841,500**	**843,000**	**843,000**
Physics and Astronomy	514,600	562,100	578,600	567,600
Planetary Exploration	205,400	220,400	205,400	217,400
Life Sciences	59,000	59,000	59,000	58,000

Table 4–1 continued

Year and Budget Item	Request	Authorization	Appropriation	Programmed (Actual)
1985 - Space Science	**1,027,400**	**1,056,400**	**1,037,400**	**1,030,400**
Physics and Astronomy	677,200	696,200	680,200	677,200
Planetary Exploration	286,900	296,900	293,900	290,900
Life Sciences	63,300	63,300	63,300	62,300
1986 - Space Science	**1,061,400**	**1,042,400**	**1,027,400**	**989,000**
Physics and Astronomy	630,400	620,400	605,400	569,300
Planetary Exploration	359,000	354,000	354,000	353,600
Life Sciences	72,000	68,000 *v*	68,000	66,100
1987 - Space Science	**973,900**	**978,000**	**972,500**	**985,000**
Physics and Astronomy	529,900 *w*	529,400	528,500	554,000
Planetary Exploration	374,300 *x*	374,300	374,300	359,200
Life Sciences	69,700 *y*	74,300 *z*	69,700	71,800
1988 - Space Science	**949,000**	**976,700**	**984,000**	**1,014,300**
Physics and Astronomy	567,100	581,800	577,100	614,400
Planetary Exploration	307,300	320,300	332,300	327,700
Life Sciences	74,600	74,600	74,600	72,200

a Undistributed. Total R&D = $3,477,200,000. House Appropriations Committee amount = $284,900,000. Senate Appropriations Committee amount = $265,500,000.
b Undistributed. Total R&D = $3,477,200,000. House Appropriations Committee amount = $181,400,000. Senate Appropriations Committee amount = $177,100,000.
c Undistributed. Total R&D = $3,477,200,000. House Appropriations Committee amount = $40,600,000. Senate Appropriations Committee amount = $40,600.00.
d Undistributed. Total R&D = $4,091,086,000.
e Undistributed. Total R&D = $4,091,086,000.
f Undistributed. Total R&D = $4,091,086,000.
g Reflects recission.
h Amended budget submission. Initial budget submission = $438,700,000.
i Reflects recission.
j Amended budget submission. Initial budget submission = $179,600,000.
k Reflects recission.

Table 4–1 continued

l Amended budget submission. Initial budget submission = $49,700,000.

m Reflects recission.

n Amended budget submission. Initial budget submission = $451,400,000.

o Undistributed. Total FY 1982 R&D basic appropriation = $4,973,100. House Appropriations Committee allocated $325,400,000 for Physics and Astronomy; Senate Appropriations Committee allocated $$340,400,000 for Physics and Astronomy. Effect of General Provision Section 501 reduced R&D appropriation to $4,740,900,000. Report of Conference Committee regarding supplemental appropriation titled "Making Urgent Supplemental Appropriations for the Fiscal Year Ending September 30, 1982, and for Other Purposes," H.R. 6685, dated July 15, 1982, allocates $325,200,000 for Physics and Astronomy (including $40,000,000 for Shuttle-Spacelab payloads).

p Amended budget submission. Initial budget submission = $245,100,000.

q Undistributed. Total FY 1982 R&D basic appropriation = $4,973,100; appropriation reflecting effect of General Provision Section 501 = $4,740,900. Report of Conference Committee regarding supplemental appropriation titled "Making Urgent Supplemental Appropriations for the Fiscal Year Ending September 30, 1982, and for Other Purposes," H.R. 6685, dated July 15, 1982, allocates $205,000,000 for Planetary Exploration.

r Amended budget submission. Initial budget submission = $49,200,000.

s Indicates basic appropriation for Life Sciences. Appropriation that reflects effects of General Provision Section 501 is undistributed. Report of Conference Committee regarding supplemental appropriation titled "Making Urgent Supplemental Appropriations for the Fiscal Year Ending September 30, 1982, and for Other Purposes," H.R. 6685, dated July 15, 1982, allocates $39,500,000 for Life Sciences.

t Senate Appropriations Committee increased amount by $38 million for Physics and Astronomy and for Planetary Exploration, of which not less than $5 million was to be used for Physics and Astronomy. Senate Appropriations Conference Committee retained $5 million for Physics and Astronomy but reduced remaining $33 million to $25 million in final appropriation.

u See footnote "p" above.

v Congressional action reduced authorized amount by $4,000,000 (undistributed).

w Amended budget submission. Original submission = $539,400,000.

x Amended budget submission. Original submission = $323,300,000.

y Amended budget submission. Original submission = $74,700,000.

z Congressional action reduced authorized amount by $400,000 (undistributed) (Authorization Committee acted on original budget submission of $74,700,000).

Table 4–2. Programmed Budget by Budget Category (in thousands of dollars)

Budget Category/Year	**1979**	**1980**	**1981**	**1982**	**1983**
Space Science	505,400	600,500	541,488	588,133	712,400
Physics and Astronomy	282,900	336,800	323,700	322,433	470,300
Lunar and Planetary *a*	182,400	219,900	175,600	210,000	186,400
Life Sciences	40,100	43,800	42,188	39,500	55,700

Budget Category/Year	**1984**	**1985**	**1986**	**1987**	**1988**
Space Science	843,000	1,030,400	989,000	985,000	1,014,300
Physics and Astronomy	567,600	677, 200	569,300	554,000	614,400
Lunar and Planetary	217,400	290,900	353,600	359,200	327,700
Life Sciences	58,000	62,300	66,100	71,800	72,200

a Renamed Planetary Exploration in FY 1980.

Table 4–3. High Energy Astronomy Observatories Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	11,400	11,400	*a*	10,647
1980	4,800	4,800	*b*	2,100

a Undistributed. House and Senate appropriations committees allocated $11,400,000.
b Undistributed.

Table 4–4. Solar Maximum Mission Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	16,200	16,200	*a*	16,700
1980	600	600	*b*	3,100

a Undistributed. House and Senate appropriations committees allocated $16,200,000.
b Undistributed.

Table 4–5. Space Telescope Development Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	79,200	79,200	*b*	79,200
1980	112,700	112,700	*c*	112,700
1981	119,300	119,300	119,300	119,300
1982	119,500	119,500	119,500	121,500
1983	137,500	137,500	137,500	182,500
1984	120,600	165,600 *d*	165,600	195,600
1985	195,000	195,000	195,000	195,000
1986	127,800	127,800	127,800	125,800
1987	95,900 *e*	95,900	95,900	96,000
1988	98,400	98,400	93,400	93,100

a Renamed Hubble Space Telescope Development in FY 1986 submission.
b Undistributed. House Appropriations Committee allocated $64,200,000. Senate Appropriations Committee allocated $79,200,000.
c Undistributed.
d House Authorization Committee increased amount for development of space telescope by $47 million; Senate Authorization Committee increased amount for space telescope by $50 million to pay for cost overruns. Conference Committee reduced Senate authorization by $5 million.
e Amended budget submission. Original submission = $27,900,000.

Table 4–6. Solar Polar Mission Development Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	13,000	13,000	*b*	12,500
1980	50,000	50,000	*c*	47,900
1981	39,600 *d*	39,600	28,000 *e*	28,000
1982	5,000 *f*	5,000	*g*	5,000 *h*
1983	21,000	21,000	6,000	6,000
1984 *i*		See Table 4–17		

a Renamed International Solar Polar Mission in FY 1980.

b Undistributed. House Appropriations Committee allocated $8,000,000. Senate Appropriations Committee allocated $13,000,000.

c Undistributed.

d Amended budget submission. Initial budget submission = $82,600,000. Decrease reflects program descoping that took place in mid-1980 to contain the amount of cost growth because of change in launch date from 1983 to 1985. The change resulted from the FY 1981 budget amendment (*NASA FY 1982 Budget Estimate,* International Solar Polar Mission Development, Objectives and Status, pp. RD 4–12).

e Reflects recission.

f Amended budget submission. Initial budget submission = $58,000,000. Decrease reflects NASA's decision to terminate the development of the U.S. spacecraft for the mission.

g Undistributed. Total FY 1982 R&D appropriation = $4,973,100,000 (basic appropriation).

h Programmed amount placed under Planetary Exploration funding beginning in FY 1982.

i Became part of Planetary Exploration program. See Table 4–7.

Table 4–7. Gamma Ray Observatory Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1981	19,100	19,100	8,200 *a*	8,200
1982	8,000 *b*	8,000	8,000	8,000
1983	34,500	34,500	34,500	34,500
1984	89,800	89,800	89,800	85,950
1985	120,200	120,200	120,200	117,200
1986	87,300	87,300	87,300	85,300
1987	51,500	51,500	51,500	50,500
1988	49,100	49,100	49,100	53,400

a Reflects recission.

b Amended budget submission. Initial budget submission = $52,000,000.

Table 4–8. Shuttle/Spacelab Payload Development Funding History (in thousands of dollars) a, b

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	38,300	38,300	*c*	34,900
1980	41,300	41,300	*d*	40,600
1981	29,100	29,100	27,400 *e*	27,400
1982	35,000 *f*	43,000	*g*	47,556
1983	81,400	81,400	81,400	81,000
1984	92,900	88,400 *h, i*	92,900	80,900
1985	105,400	113,400	105,400	105,400
1986	135,500	125,500	110,500	89,400
1987	84,600 *j*	84,100	84,600	72,800 *k*
1988	75,400	75,400	80,400	47,800 *l*

a Included mission management beginning FY 1981.

b Incorporated Space Station Payload Development and mission management beginning in FY 1986.

c Undistributed. Both House and Senate appropriations committees allocated $38,300,000.

d Undistributed.

e Reflects recission.

f Amended budget submission. Initial budget submission = $51,800,000.

g Undistributed. FY 1982 R&D basic appropriation = $4,973,100. R&D appropriation reflecting effects of General Provision Section 501 = $5,740,900. House Appropriations Committee allocation for Shuttle/Spacelab Payload Development = $35,000,000. Senate Appropriations Committee allocation for Shuttle/Spacelab Payload Development = $40,000,000. Supplemental appropriations bill Conference Committee report indicates allocation of $40,000,000 for Shuttle/Spacelab Payload Development.

h Senate Authorization Committee reduced amount authorized for solar optical telescope by $1.6 million to offset space telescope increases and added $5 million for space plasma laboratory. Conference Committee added $2.5 million for space plasma laboratory and decreased by $7 million amount authorized for solar optical telescope.

i Amended budget submission. Original budget submission = $95,400,000.

j Amended budget submission. Original budget submission = $115,100,000.

k Included $5 million for astrophysics payloads and $4.6 million for space physics payloads.

l Additional $8.1 million for astrophysics payloads and $9.9 million for space physics payloads were added to programmed amount.

Table 4–9. Explorer Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	29,800	29,800	*a*	31,288
1980	30,400	30,400	*b*	32,300
1981	33,000	33,000	33,000	33,300
1982	36,600	36,600	36,600	33,300
1983	34,300	34,300	34,300	34,300
1984	48,700	48,700	48,700	48,700
1985	51,900	51,900	51,900	51,900
1986	55,200	55,200	55,200	48,200
1987	56,700	56,700	56,700	55,700
1988	60,300	70,300	70,300	67,900

a Undistributed. Both House and Senate appropriations committees allocated $29,800,000 for Explorer Development.

b Undistributed.

Table 4–10. Physics and Astronomy Mission Operations and Data Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	32,400	32,400	*a*	25,453
1980	36,500	36,500	*b*	37,100
1981	38,900	38,900	38,900	38,900
1982	47,000 *c*	47,000	47,000	45,300
1983	85,600	86,600 *d*	85,600	61,400
1984	79,500	80,500 *e*	79,500	68,100
1985	109,100	109,100	109,100	109,100
1986	119,900	119,900	119,900	111,700
1987	125,700 *f*	125,700	125,700	131,000
1988	128,100	128,100	128,100	140,500

a Undistributed. Both House and Senate appropriations committees allocated $32,400,000.

b Undistributed.

d Amended budget submission. Initial budget submission = $53,500,000.

d House Authorization Committee reduced amount to be allocated for Space Shuttle/Solar Maximum Mission Spacecraft Retrieval by $9.2 million to $77,400,000 and increased amount by $1 million for data analysis for HEAO and OAO. Senate Authorization Committee increased the amount to $93,600,000 to counter "slow progress in future programs and basic technology areas." (Footnote "d" accompanying *Chronological History of the FY 1983 Budget Submission,* prepared by NASA Comptroller, Budget Operations Division.) Authorization Conference Committee reduced increase to $1 million over submission.

e House Authorization Committee increased amount for HEAO by $1 million.

f Amended budget submission. Original budget submission = $172,700,000.

Table 4–11. Physics and Astronomy Research and Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	35,900	35,900	*a*	44,005
1980	34,300	34,300	*b*	33,774
1981	36,700 *c*	42,800	basic: 42,800 reflects Sec. 412: 38,000	37,700
1982	38,000 *d*	38,000	38,000	22,935
1983	39,200	39,200 *e*	39,200	28,500
1984	29,800	35,800 *f*	49,800 *g*	35,873
1985	36,900	47,900	39,900	111,700
1986	42,300	42,300	42,300	49,000
1987	51,100	51,100	49,700	53,400
1988	60,100	60,100	60,100	82,900 *h*

a Undistributed. Both House and Senate appropriations committees allocated $35,900,000 for Research and Analysis.

b Undistributed.

c Amended budget submission. Original budget submission = $42,800,000.

d Amended budget submission. Original budget submission = $42,500,000.

e See footnote “c” in Table 4–10.

f House Authorization Committee increased authorization for Universities Basic Research program by $4 million and Universities Research Instrumentation by $2 million. Senate Authorization Committee increased Universities Basic Research by $4 million.

g House and Senate appropriation committees increased appropriation by $20 million for Physics and Astronomy and Planetary Exploration at NASA’s discretion.

h Additional $10.3 million for Shuttle Test of Relativity Experiment added to programmed amount.

Table 4–12. Physics and Astronomy Suborbital Programs Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	29,300	29,300	*a*	28,207
1980	26,900	26,900	*b*	27,226
1981	30,900	30,900	30,900	39,900
1982	35,500*c*	35,500	35,500	43,842
1983	38,200	39,200*d*	38,200	48,100
1984	53,300	53,300	52,300	52,477
1985	58,700	58,700	58,700	58,700
1986	62,400	62,400	62,400	59,900
1987	64,400	64,400	64,400	79,100
1988	75,700	80,400	75,700	44,700

a Undistributed. Both House and Senate appropriations committees allocated $29,300,000 for Suborbital Programs.

b Undistributed.

c Amended budget submission. Original budget submission = $37,500,000.

d See footnote “c” in Table 4–10.

Table 4–13. Space Station Planning Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1987 *a*	—	—	—	18,900
1988	20,000 *b*	20,000	20,000	15,500

a Space Station Planning not included in budget estimates or appropriation for FY 1987 as separate budget item. Incorporated in Spacelab/Space Station Payload Development and Mission Management Budget category.

b Increased budget submission from $0 to $20,000,000.

Table 4–14. Jupiter Orbiter/Probe and Galileo Programs Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	78,700	78,700	*b*	78,700
1980	116,100	116,100	*c*	116,100
1981	63,100	63,100	63,100	63,100
1982	108,800	108,000	108,000	115,700
1983	92,600	92,600	91,600	91,600
1984	79,500	79,500	79,500	79,500
1985	56,100	56,100	56,100	58,800
1986	39,700	39,700	39,700	64,200
1987	77,000 *d*	77,000	77,000	71,200
1988	55,300	55,300	55,300	51,900

a Renamed Galileo Development in FY 1981.

b Undistributed. House Appropriations Committee allocated $68,700,000. Senate Appropriations Committee allocated $78,700,000.

c Undistributed.

d Reflects budget amendment that increased budget submission from $0 to $77,000,000

Table 4–15. Venus Radar Mapper/Magellan Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1984	29,000	29,000	29,000	29,000
1985	92,500	92,500	92,500	92,500
1986	112,000	112,000	112,000	120,300
1987	69,700 *a*	69,700	69,700	97,300
1988	59,600	59,600	59,600	73,000

a Amended budget submission. Original budget submission = $66,700,000.

Table 4–16. Global Geospace Science Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1988	—	—	—	18,600

a Global Geospace Science was previously budgeted under Environmental Observations (Applications). There was no specific budget amount for Global Geospace Science in the FY 1988 budget submission. However, the Senate report, which accompanied the FY 1988 appropriations bill (H.R. 2783, September 25, 1987), indicated that NASA had requested $25,000,000 for the program for FY 1988. NASA's FY 1988 budget submission for Environmental Observations = $393,800,000, the authorization = $393,800,000, and the appropriation = $378,800,00. These figures were compiled prior to the OSSA reorganization. For the FY 1988 budget year that coincided with the OSSA reorganization, Global Geospace Science was moved to Physics and Astronomy.

Table 4–17. International Solar Polar Mission/Ulysses Development Funding History (in thousands of dollars) a, b

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1984 *c*	8,000	8,000	8,000	6,000
1985	9,000	9,000	9,000	9,000
1986	5,600	5,600	5,600	8,800
1987	24,000 *d*	24,000	24,000	10,300
1988	10,800	10,800	10,800	7,800

a Renamed International Solar Polar Mission in FY 1980.
b Renamed Ulysses in FY 1986 submission.
c Moved from Physics and Astronomy Management (see Table 4–6).
d Reflects budget amendment that increased budget submission from $0 to 24,000,000.

Table 4–18. Mars Geoscience/Climatology Orbiter Program Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1985	16,000	16,000	16,000	13,000
1986	43,800	38,800	38,800	33,800
1987	62,900	62,900	62,900	35,800
1988	29,300	42,300	54,300	53,900

a Renamed Mars Observer in FY 1986 submission.

Table 4–19. Lunar and Planetary Mission Operations and Data Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	84,400	84,400	*a*	59,300
1980	59,000	59,000	*b*	58,800
1981	60,500 *c*	64,800	basic: 64,800 reflects Sec. 412: 61,800	61,800
1982	45,800 *d*	45,800	45,800	42,600
1983	26,500	38,500	26,500	38,500
1984	43,400	43,400	43,400	43,400
1985	58,800	58,800	58,800	56,100
1986	95,000	95,000	95,000	67,000
1987	77,200 *e*	77,200	77,200	75,100
1988	77,000	77,000	77,000	73,792

a Undistributed. House Appropriations Committee allocated $84,400,000. Senate Appropriations Committee allocated $78,700,000.
b Undistributed.
c Amended budget submission. Initial budget submission = $64,800,000.
d Amended budget submission. Initial budget submission = $50,900,000.
e Amended budget submission. Initial budget submission = $130,200,000.

Table 4–20. Lunar and Planetary Research and Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	24,000	24,000	*a*	44,400
1980	45,100	45,100	*b*	45,000
1981	51,700	51,700	basic: 51,700 reflects Sec. 412: 50,700	50,700
1982	51,500 *c*	51,500	*d*	46,700
1983	35,500	46,500	37,300	50,300
1984	45,500	60,500	45,500	59,500
1985	54,500	64,500	61,500	61,500
1986	62,900	62,900	62,900	59,500
1987	63,500	63,500	63,500	69,500
1988	75,300	75,300	75,300	67,308

a Undistributed. Both House and Senate appropriations committees allocated $24,000,000.
b Undistributed.
c Amended budget submission. Original budget submission = $57,200,000.
d Undistributed. Total R&D (basic appropriation) = $4,973,100.000. R&D appropriation reflecting Sec. 501 = $4,740,900,000.

Table 4–21. Life Sciences Flight Experiments Program Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	12,400	14,400	*a*	15,700
1980	12,900	12,900	*b*	16,600
1981	12,700 *c*	14,700	12,700	12,700
1982	14,000 *d*	14,000	14,000	14,000
1983	24,000	24,000	24,000	24,000
1984	23,000	23,000	23,000	23,000
1985	27,100	27,100	27,100	27,100
1986	33,400	33,400	33,400	32,100
1987	31,700 *e*	36,700	31,700	30,000
1988	32,900	32,900	32,900	33,800

a Undistributed. Both House and Senate appropriations committees allocated $12,400,000.
b Undistributed.
c Amended budget submission. Initial budget submission = $19,200,000.
d Amended budget submission. Initial budget submission = $16,500,000.
e Amended budget submission. Initial budget submission = $36,700,000.

Table 4–22. Life Sciences/Vestibular Function Research Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual) *a*
1979	3,800	3,800	*b*	—
1980	3,700	3,700	*c*	—

a No amount programmed specifically for Vestibular Function Research. Included in Space Biology Research to be conducted on the orbital flight test or Spacelab 1 mission.
b Undistributed. Both House and Senate appropriations committees allocated $3,800,000.
c Undistributed.

Table 4–23. Life Sciences Research and Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	24,400	24,400	*a*	24,400
1980	27,300	27,300	*b*	27,200
1981	26,400 *c*	30,500	basic: 30,500 reflects Sect. 412: 29,488	29,488
1982	29,500 *d*	29,500	29,500	25,500
1983	31,700	31,700	31,700	31,700
1984	36,000	36,000	36,000	35,000
1985	36,200	36,200	36,200	35,200
1986	38,600	38,600	38,600	34,000
1987	63,500	63,500	63,500	41,800
1988	41,700	41,700	41,700	38,400

a Undistributed. Both House and Senate appropriations committees allocated $24,400,000.

b Undistributed.

c Amended budget submission. Initial budget submission = $30,500,000.

d Amended budget submission. Initial budget submission = $32,700,000.

Table 4–24. Science Missions (1979–1988)

Date	Mission	Discipline/Program Sponsor
Jan. 30, 1979	Spacecraft Charging at High Altitudes	Solar Terrestrial/U.S. Air Force
June 2, 1979	UK-6 (Ariel)*	Astrophysics/U.K. Science Research Council
Aug. 10, 1979	High Energy Astronomy Observatory-3 (HEAO)	Astrophysics
Feb. 14, 1980	Solar Maximum Mission	Solar Terrestrial
Aug. 3, 1981	Dynamics Explorer 1 and 2	Solar Terrestrial and Astrophysics
Oct. 6, 1981	Solar Mesosphere Explorer	Solar Terrestrial and Astrophysics
March 22, 1982	OSS-1 (STS-3)	Spacelab
Jan. 25, 1983	Infrared Astronomy Satellite (IRAS)	Astrophysics
May 26, 1983	European X-Ray Observatory Satellite (EXOSAT)*	Astrophysics/European Space Agency
June 22, 1983	Shuttle Pallet Satellite (SPAS)-01	Platform for science experiments/Germany
June 27, 1983	Hilat*	Astrophysics/U.S. Air Force
Nov. 28, 1983	Spacelab 1 (STS-9)	Spacelab (multidiscipline)
Aug. 16, 1984	Active Magnetospheric Particle Tracer Explorers (AMPTE)	Astrophysics
April 29, 1985	Spacelab 3 (STS 51-B)	Spacelab (multidiscipline)
June 17, 1985	Spartan-1	Astrophysics
July 29, 1985	Spacelab 2 (STS 51-F)	Spacelab (multidiscipline)
July 29, 1985	Plasma Diagnostic Package (PDP)	Earth Sciences and Applications
Oct. 30, 1985	Spacelab D-1 (STS 61-A)	German Spacelab (multidiscipline)
Jan. 23, 1986	Spartan 203 (Spartan-Halley) (failed to reach orbit)	Astrophysics
Nov. 13, 1986	Polar Bear*	Astrophysics/U.S. Air Force
March 25, 1988	San Marco D/L	Astrophysics

* NASA provided launch service or other nonscience role.

Table 4–25. Spacecraft Charging at High Altitudes Characteristics

Launch Date/Range	January 30, 1979/Eastern Test Range
Date of Reentry	Turned off May 28, 1991
Launch Vehicle	Delta 2914
NASA Role	Launch services for U.S. Air Force and three experiments
Responsible (Lead) Center	Goddard Space Flight Center
Mission Objectives	Place the Air Force satellite into a highly elliptical orbit of sufficient accuracy to allow the spacecraft to achieve its final elliptical orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Instruments and Experiments (NASA experiments were the Light Ion Mass Spectrometer, the Electric Field Detector, and the Magnetic Field Monitor)	1. Satellite Surface Potential Monitor measured the potential of a sample surface of various compositions and aspects relative to vehicle ground or to the reference surface by command. 2. Charging Electrical Effect Analyzer measured the electromagnetic background induced in the spacecraft as a result of the charging phenomena. 3. Spacecraft Sheath Electric Fields measured the asymmetric sheath-electric field of the spacecraft, the effects of this electric field on particle trajectories near the spacecraft, and the current to the spherical probe surfaces mounted on booms at distances of 3 meters from the spacecraft surface. 4. Energetic Proton Detector measured the energetic proton environment of the trapped particles at spacecraft altitudes with energies of 20 to 1,000 keV, in six or more differential channels, plus an integral flux in the range from 1 to 2 MeV. 5. High Energy Particle Spectrometer measured the flux, spectra, and pitch angle distribution of the energetic electron plasma in the energy range of 100 keV to >3000 keV, the proton environment at energies between 1 MeV and 100 MeV, and the alpha particle environment between 6 MeV and 60 MeV during the solar particle events. 6. Satellite Electron Beam System consisted of an indirectly heated, oxide-coated cathode and a control grid. It controlled the ejection of electrons from the spacecraft. 7. Satellite Positive Ion Beam System consisted of a Penning discharge chamber ion source and a control grid. It controlled the ejection of ions from the spacecraft. 8. Rapid Scan Particle Detector measured the proton and electron temporal flux variations from 50eV to 60 keV for protons and 50 eV to 10 MeV for electrons, with an ultimate time resolution of milliseconds.

Table 4–25 continued

	9. Thermal Plasma Analyzer measured, by retarding potential analysis, the environmental photo and secondary electron densities and temperatures, in the range of 10^{-1} to 10^{4} electrons per cubic centimeter, for electrons of energies in the range 0 eV to 100 eV.
	10. Light Ion Mass Spectrometer used magnetic mass analysis and retarding potential analysis for temperature determination. It measured the ion density and temperature in the energy range of 0.01 to 100 eV and in the density range of 0.01 to 1,000 ions/cm^3.
	11. Energetic Ion Composition Experiment determined momentum and energy per charge and measured ions in the mass range of 1 to 150 AMU per charge with energies of 100 eV to 20,000 eV.
	12. San Diego Particles Detectors measured protons and electrons in the energy range 1 eV to 80,000 eV in 64 discrete steps. This experiment measured the particle flux to the spacecraft, overall charge of the spacecraft, differential charge on parts of the spacecraft, and charge accumulated on selected material samples. It also measured the ambient plasma and detected oscillations, enabling better predictions of magnetosphere dynamics.
	13. Electric Field Detector measured AC and DC electric fields in the tenuous plasma region of the outer magnetosphere.
	14. Magnetic Field Monitor measured the magnetic flux density in the range ±5 milligauss with a resolution of 0.004 milligauss.
	15. Thermal Coatings monitored temperatures of insulated material samples to determine the changes that took place in their solar absorptive and emissive characteristics with time exposure in space.
	16. Quartz Crystal Microbalance measured the deposition rate of contaminants (mass) as a function of energy in the axial and radial directions, respectively.
Orbit Characteristics:	
Apogee (km)	43,251
Perigee (km)	27,543
Inclination (deg.)	7.81
Period (min.)	1,416.2
Weight (kg)	655
Dimensions	Diameter of 172.7 cm; length of 174.5 cm
Shape	Cylindrical
Power Source	Solar arrays
Prime Contractor	SAMSO, Martin Marietta Aerospace Corp.

Table 4–26. UK-6 (Ariel) Characteristics

Launch Date/Range	June 2, 1979/Wallops Flight Center
Date of Reentry	Switched off March 1982; reentered September 23, 1990
Launch Vehicle	Scout
NASA Role	Launch services for United Kingdom Science Research Council
Responsible (Lead) Center	Langley Research Center
Mission Objectives	Place the UK-6 satellite in an orbit that will enable the successful achievement of the payload scientific objectives: • Measure the charge and energy spectra of galactic cosmic rays, especially the ultraheavy component • Extend the x-ray astronomy to lower levels by examining the spectra, structure, and position of intrinsically low energy sources, extend the spectra of known sources down to low energies, and study the low-energy diffuse component • Study the fast periodic and aperiodic fluctuations in x-ray emissions from a number of low galactic latitude sources and improve the knowledge of the continuum spectra of the sources being observed.
Instruments and Experiments	1. Cosmic Ray Experiment measured the charge and energy spectra of the ultraheavy component of cosmic radiation with particular emphasis on the charge region of atomic weights above 30 (Bristol University). 2. Leicester X-Ray Experiment investigated the periodic and aperiodic fluctuations in emissions from a wide range of x-ray sources, down to submillisecond time scales (Leicester University). 3. MSSL/B X-Ray Experiment studied discrete sources and extended features of the low-energy x-ray sky in the range of 0.1 to 2 keV. It also studied long- and short-term variability of individual x-ray sources (Mullar Space Laboratory of University College, London and Birmingham University). 4. Solar Cell Experiment investigated the performance in orbit of new types of solar cells mounted on a flexible, lightweight support (Royal Aircraft Establishment). 5. CMOS Experiment was a complementary metal oxide semiconductor (CMOS) electronics experiment that investigated the susceptibility of these devices to radiation in a space environment (Royal Aircraft Establishment).

Table 4–26 continued

Orbit Characteristics:	
Apogee (km)	656
Perigee (km)	607
Inclination (deg.)	55.04
Period (min.)	97
Weight (kg)	154.5
Dimensions	n/a
Shape	Cylindrical
Power Source	Solar array and battery power
Prime Contractor	Marconi Space and Defense Systems, Ltd.
Results	The satellite lasted beyond its 2-year design life. However, it lost at least half its data. It suffered from radio interference from Earth, which caused the high-voltage supplies and its tape recorder to switch on and off sporadically and to lose information that should have been stored. The problem was alleviated by using more NASA ground stations, an Italian receiving station in Kenya, and a portable station set up by University College in Australia.

Table 4–27. HEAO-3 Characteristics

Launch Date/Range	September 20, 1979/Eastern Test Range
Date of Reentry	December 7, 1981
Launch Vehicle	Atlas-Centaur
NASA Role	Project management
Responsible (Lead) Center	Marshall Space Flight Center
Mission Objectives	Study gamma ray emission with high sensitivity and resolution over the energy range of about 0.06 MeV to 10 MeV and measure the isotopic composition of cosmic rays from lithium through iron and the composition of cosmic rays heavier than iron
Instruments and Experiments	1. High-Spectral Resolution Gamma Ray Spectrometer (Jet Propulsion Laboratory) explored sources of x-ray and gamma ray line emissions from approximately 0.06 to 10 million electron volts. It also searched for new discrete sources of x-rays and gamma rays and measured the spectrum and intensity of Earth's x-ray and gamma ray albedo (Figure 4–3). 2. Isotopic Composition of Primary Cosmic Rays (Center for Nuclear Studies, France, and Danish Space Research Institute) measured the isotopic composition of primary cosmic rays with atomic charge Z between Z=4 (beryllium) to Z=26 (iron) and in the momentum range from 2 to 20 giga electron volts per nucleon (Figure 4–4). 3. Heavy Nuclei Experiment (Washington University, California Institute of Technology, and University of Minnesota) observed rare, high-atomic-number (Z>30), relativistic nuclei in the cosmic rays. It also measured the elemental composition and energy spectra of these nuclei with sufficient resolution to determine the abundance of individual elements from chlorine (Z=17) through at least uranium (Z=92). These data provided information on nucleosynthesis models and on the relative importance of different types of stellar objects as cosmic ray sources (Figure 4–5).
Orbit Characteristics:	
Apogee (km)	504.9
Perigee (km)	486.4
Inclination (deg.)	43.6
Period (min.)	94.5
Weight (kg)	2,904
Dimensions	Diameter of 2.35 m; length of 5.49 m
Shape	Cylindrical with solar panels (two modules: experiment and equipment)
Power Source	Solar arrays and nickel cadmium batteries
Prime Contractor	TRW Systems, Inc.
Results	Mission was highly successful; the satellite returned data for 20 months.

Table 4–28. Solar Maximum Mission

Launch Date/Range	February 14, 1980/Eastern Test Range
Date of Reentry	December 2, 1989
Launch Vehicle	Delta 3910
NASA Role	Project management
Responsible (Lead) Center	Goddard Space Flight Center
Mission Objectives	Observe a sizable number of solar flares or other active-Sun phenomena simultaneously by five or six of the Solar Maximum Mission experiments, with coalignment of the narrow field-of-view instruments, and measure the total radiative output of the Sun over a period of at least 6 months with an absolute accuracy of 0.5 percent and short-term precision of 0.2 percent
Instruments and Experiments (Figure 4–6)	1. Gamma Ray Spectrometer measured the intensity, energy and Doppler shift of narrow gamma ray radiation lines and the intensity of extremely broadened lines. 2. Hard X-Ray Spectrometer helped determine the role that energetic electrons played in the solar flare phenomenon. 3. Hard X-Ray Imaging Spectrometer imaged the Sun in hard x-rays and provided information about the position, extension, and spectrum of the hard x-ray bursts in flares. 4. Soft X-Ray Polychromator investigated solar activity that produced solar plasma temperatures in the 1.5 million to 50 million degree range. It also studied solar plasma density and temperature. 5. Ultraviolet Spectrometer and Polarimeter studied the ultraviolet radiation from the solar atmosphere, particularly from active regions, flares, prominences, and active corona, and studied the quiet Sun. 6. High Altitude Observatory Coronagraph/Polarimeter returned imagery of the Sun's corona in parts of the visible spectrum as part of an investigation of coronal disturbances created by solar flares. 7. Solar Constant Monitoring Package monitored the output of the Sun over most of the spectrum and over the entire solar surface.
Orbit Characteristics:	
Apogee (km)	573.5
Perigee (km)	571.5
Inclination (deg.)	28.5
Period (min.)	96.16
Weight (kg)	2,315.1
Dimensions	Diameter of 2.1 m; length of 4 m
Power Source	Solar arrays
Prime Contractor	Goddard in-house

Table 4–28 continued

Results/Remarks	This mission was judged successful based on the results of the mission with respect to the approved prelaunch objectives. For the first 9 months of operation, the mission continuously gathered data from seven experiments on board. These data represented the most comprehensive information ever collected about solar flares. Project scientists gained valuable insight into the mechanisms that trigger solar flares and significant information about the total energy output from the Sun. The payload of instruments gathered data collectively on nearly 25 flares. After 9 months of normal operation, the satellite's attitude control system lost its capability to point precisely at the Sun. At that point, the spacecraft was placed in a slow spin using a magnetic control mode, which permitted continued operation of three instruments while coarsely pointing at the Sun. This was the first NASA satellite designed to be retrieved and serviced by the Space Shuttle. The Solar Max Repair Mission (STS 41-C) was successful and was completed after 7 hours, 7 minutes of extravehicular activity. Following its repair, Solar Max discovered several comets as well as continuing with its planned solar observations.

Table 4–29. Dynamics Explorer 1 and 2 Characteristics

Launch Date/Range	August 3, 1981/Western Test Range
Date of Reentry	Dynamics Explorer 1 retired February 28, 1991, Dynamics Explorer 2 reentered February 19, 1983
Launch Vehicle	Delta 3913
NASA Role	Project management
Responsible (Lead) Center	Goddard Space Flight Center
Mission Objectives	Investigate the strong interactive processes coupling the hot, tenuous, convecting plasmas of the magnetosphere and the cooler, denser plasmas and gases co-rotating in Earth's ionosphere, upper atmosphere, and plasmasphere
Instruments and Experiments	Dynamics Explorer 1: 1. High Altitude Plasma Instrument (five electrostatic analyzers) measured phase-space distributions of electrons and positive ions from 5 eV to 25 eV as a function of pitch angle. 2. Retarding Ion Mass Spectrometer (magnetic ion mass spectrometer) measured density, temperature, and bulk flow of H+, He+, and O+ in high-altitude mode, and composition in the 1–64 AMU range in low-altitude mode. 3. Spin-Scan Auroral Imager (spin-scan imaging photometers) imaged aurora at visible and ultraviolet and made photometric measurements of the hydrogen corona. 4. Plasma Waves (long dipole antennae and a magnetic loop antenna) measured electric fields from 1 hertz (Hz) to 2 MHz, magnetic fields from 1 Hz to 400 kHz, and the DC potential difference between the electric dipole elements. 5. Hot Plasma Composition (energetic ion mass spectrometer) measured the energy range from 0 keV to 17 keV per unit charge and the mass range from 1 AMU to 138 AMU per unit charge. 6. Magnetic Field Observations (fluxgate magnetometer) measured field-aligned currents in the auroral oval and over the polar cap at two altitudes. Dynamics Explorer 2: 1. Langmuir Probe (cylindrical electrostatic probe) measured electron temperature and electron or ion concentration. 2. Neutral Atmosphere Composition Spectrometer (mass spectrometer) measured the composition of the neutral atmosphere. 3. Retarding Potential Analyzer measured ion temperature, ion composition, ion concentration, and ion bulk velocity. 4. Fabray-Periot Interferometer measured drift and temperature of neutral ionic atomic oxygen. 5. Ion Drift measured bulk motions of ionospheric plasma.

Table 4–29 continued

	6. Vector Electric Field Instrument (triaxial antennas) measured electric fields at ionospheric altitudes and extra-low-frequency and low-frequency ionosphere irregularities. 7. Wind and Temperature Spectrometer (mass spectrometer) measured in-situ, neutral winds, neutral particle temperatures, and the concentration of selected gases. 8. Magnetic Field Observations (see Dynamics Explorer 1 above) 9. Low Altitude Plasma Instrument (plasma instrument) measured positive ions and electrons from 5 eV to 30 keV.	
Orbit Characteristics:	Dynamics Explorer 1	Dynamics Explorer 2
Apogee (km)	23,173	1,012.5
Perigee (km)	569.5	309
Inclination (deg.)	89.91	89.99
Period (min.)	409	97.5
Weight (kg)	424	
Dimensions	Width of 134.6 cm; length of 114.3 cm	
Shape	16-sided polygon	
Power Source	Solar cell arrays	
Prime Contractor	RCA	
Results	The spacecraft achieved a final orbit somewhat lower than planned because of short burn of the second stage in the Delta launch vehicle, but could still carry out the full scientific mission.	

Table 4–30. Solar Mesospheric Explorer Instrument Characteristics

Instrument	Detector	Spectral Range	Δλ	Total Shaft Angle	At Exit Slit	Full Width at Half Maximum	Grating Steps per Scan	Δλ Per Step
Ultraviolet	Channel A, 510 F	1,900–3,100	1,200		18Å/mm	15Å	208/11	4.8Å/91Å/ step
Ozone				14.4˚				
Experiment	Channel B, 520F	2,300–3,500	1,200		First Order	123Å	512	44Å/step
	Channel A							
1.27μ	(Lead Sulfide)	1.1μ–2.5μ	1.4μ					
Airglow				13.4˚	384Å/mm	123Å	512	44Å/step
Experiment	Channel B							
	(Lead Sulfide)	1.1μ–2.5μ	1.4μ					
	Channel A	4,390–4,420				9.8Å		3.2Å/step
Visible NO_2			2,800Å	21.6˚	28Å/mm		512/438	
Experiment	Channel B, 510 N	2,900–5,700				19.6Å		6.4Å/step
Solar	Channel A, 510F	1,800-3,100	1,250Å					
Ultraviolet				9.7˚	30Å/mm	14Å	512	2.6Å/step
Monitor	Channel B, 510F	1,200-2,540	1,250Å					
Four-	Channel A, 15.1μ	17.2–13.2μ	—			4.0μ		
Channel	Channel B, 15.5μ	15.7–14.7μ	—	—	—	1.0μ	—	—
Infrared	Channel C, 9.6μ	10.6–8.6μ	—			2.0μ		
Radiometer	Channel D, 6.3μ	7.2–6.1μ	—			1.1μ		

Table 4–31. Solar Mesospheric Explorer Characteristics

Launch Date/Range	October 6, 1981/Western Test Range
Date of Reentry	March 5, 1991
Launch Vehicle	Delta 2310
NASA Role	Project management
Responsible (Lead) Center	Jet Propulsion Laboratory
Mission Objectives	Investigate the processes that create and destroy ozone in Earth's mesosphere and upper stratosphere, with the following specific goals: • Determine the nature and magnitude of changes in ozone densities that result from changes in the solar ultraviolet flux • Determine the interrelationship among the solar flux, ozone, and the temperature of the upper stratosphere and mesosphere • Determine the interrelationship between water vapor and ozone • Determine the interrelationship between nitrogen dioxide (NO_2) and ozone • If a significant number of solar proton events occur, determine the relationship between the magnitude of the decrease in ozone and the flux and energy of the solar protons, the recovery rate of ozone following the event, and the role of water vapor in the solar proton destruction of ozone • Incorporate the results of the SME mission in a model of the upper stratosphere and mesosphere that could predict the future behavior of ozone
Instruments and Experiments	1. Ultraviolet Ozone Spectrometer measured ozone between 40 km and 70 km altitude. 2. 1.27-Micron Spectrometer measured ozone between 50 km and 90 km altitude and hydroxyl between 60 km and 90 km. 3. Nitrogen Dioxide Spectrometer measured NO_2 between 20 km and 40 km altitude. 4. Four-Channel Infrared Radiometer measured temperature and pressure between 20 km and 70 km altitudes and water vapor and ozone between 30 km and 65 km altitude. 5. Ultraviolet Solar Monitor looked 45 degrees from the spacecraft rotation axis to scan through the Sun once each revolution of the spacecraft. The instrument measured the amount of incoming solar radiation from 1,700 Angstroms to 3,100 Angstroms and at 1,216 Angstroms. 6. Proton Alarm Sensor monitored the amount of integrated solar protons from 30 to 500 million eV. 7. Spatial Reference Unit controlled the timing for data gating from the instruments.

Table 4–31 continued

Orbit Characteristics:	
Apogee (km)	534
Perigee (km)	533
Inclination (deg.)	98.0
Period (min.)	95.3
Weight (kg)	437
Dimensions	Diameter of 1.25 m; length of 1.7 m
Shape	Cylindrical
Power Source	Solar cell array
Prime Contractor	University of Colorado's Laboratory for Atmospheric and Space Physics, Ball Aerospace Systems Division
Remarks	The mission objective was accomplished by measuring ozone parameters and the processes in the mesosphere and upper stratosphere that determined their values. All mission events occurred as planned and on schedule.

Table 4–32. Infrared Astronomy Satellite Characteristics

Launch Date/Range	January 25, 1983/Western Test Range
Date of Reentry	Ceased operations November 21, 1983
Launch Vehicle	Delta 3910
NASA Role	Provided telescope, tape recorders, launch vehicle, data processing, co-chairman and members of the Joint IRAS Science Working Group
Responsible (Lead) Center	Jet Propulsion Laboratory—overall project management; Ames Research Center—management of the infrared telescope system until integrated with spacecraft
Mission Objectives	Obtain basic scientific data about infrared emissions throughout the total sky, to reduce and analyze these data, and to make these data and results available to the public and the scientific community in a timely and orderly manner
Instruments and Experiments	1. Ritchey-Chretien telescope detected infrared radiation in the region of 9 to 119 microns and observed emissions of infrared energy as faint as one million-trillionth of a watt per square centimeter. 2. Dutch Additional Experiment: • Low-Resolution Spectrometer acquired spectra of strong infrared point sources observed by the main telescope in the wavelength range from 7.4 to 23 microns. • Short-Wavelength Channel Detector obtained information on the distribution of stars in areas of high stellar density. It provided statistical data on the number of infrared sources. 3. Long-Wavelength Photometer mapped infrared sources that radiated in two wavelength bands simultaneously—from 41 to 62.5 microns and from 84 to 114 microns.
Orbit Characteristics:	
Apogee (km)	911
Perigee (km)	894
Inclination (deg.)	99.1
Period (min.)	103
Weight (kg)	1,076
Dimensions	Diameter of 2.1 m; length of 3.7 m
Shape	Cylindrical
Power Source	Two deployable solar panels
Prime Contractor	Ball Aerospace Systems Division in the United States; Fokker Schipol in The Netherlands

Table 4–32 continued

Results	During its 300 days of observations, IRAS carried out the first complete survey of infrared sky. On-board instruments with four broad infrared photometry channels (8 to 120 microns) detected unidentified cold astronomical objects, bands of dust in the solar system, infrared cirrus clouds in interstellar space, infrared radiation from visually inconspicuous galaxies, and possible beginnings of new solar systems around Vega and other stars. IRAS investigated selected galactic and extragalactic sources and mapped extended sources. The mission provided a complete and systematic listing of discrete sources in the form of sky and source catalogs. More than 2x1011 bits of data were received from IRAS. IRAS also discovered five new comets.

Table 4–33. European X-Ray Observatory Satellite Characteristics

Launch Date/Range	May 26, 1983/Western Space and Missile Center
Date of Reentry	May 6, 1986
Launch Vehicle	Delta 3914
NASA Role	Launch support for European Space Agency
Responsible (Lead) Center	Goddard Space Flight Center
Mission Objectives	Launch the EXOSAT spacecraft into an elliptical polar orbit on a three-stage Delta 3914 launch vehicle with sufficient accuracy to allow the spacecraft to accomplish its scientific mission
Payload Objectives	Make a detailed study of known x-ray sources and identify new x-ray sources
Instruments and Experiments	1. X-Ray Imaging Telescopes (2) 2. Large Area Proportional Counter Array 3. Gas Scintillation Proportional Counter Spectrometer
Orbit Characteristics:	
Apogee (km)	194,643
Perigee (km)	6,726
Inclination (deg.)	72.5
Period (min.)	58,104 (4.035 days)
Weight (kg)	510
Dimensions	Diameter of 2.1 m; height of 1.35 m
Shape	Box
Power Source	Solar array
Prime Contractor	European Cosmos Consortium headed by Messerschmitt-Bolkow-Blohm (MBB)

Table 4–34. Shuttle Pallet Satellite-01 Characteristics

Launch Date/Range	Released from cargo bay June 22, 1983
Date of Reentry	Retrieved June 24, 1983
NASA Role	Provided Shuttle launch for Messerschmitt-Bolkow-Blohm (MBB), BMFT, and European Space Agency, for reduced fee
Launch Vehicle	STS-7 (*Challenger*)
Responsible (Lead) Center	n/a
Mission Objectives	Launch and retrieve the reusable SPAS
Instruments and Experiments	1. Microgravity experiments with metal alloys 2. Microgravity experiments with heat pipes 3. Microgravity experiments with pneumatic conveyors 4. An instrument that can control a spacecraft's position by observing Earth below 5. Remote sensing "push-broom" scanner that can detect different kinds of terrain and land/water boundaries 6. Mass spectrometer for monitoring gases in the cargo bay and around the orbiter's thrusters 7. Experiment for calibrating solar cells 8. A series of tests in which the Remote Manipulator System arm released the pallet to fly in space and then retrieved it and restowed it in the cargo bay
Orbit Characteristics:	
Apogee (km)	300
Perigee (km)	295
Inclination (deg.)	28.5
Period (min.)	90.5
Weight (kg)	2,278
Dimensions	Length of 4.8 m; height of 3.4 m; width of 1.5 m
Shape	Rectangular
Power Source	Battery power while outside orbiter; orbiter power while in cargo bay
Prime Contractor	MBB
Remarks	All experiment activities, planned detailed test objectives, and detailed secondary objectives were accomplished on schedule. The mission carried out successful detached and attached operations. It performed scientific experiments, tested the remote manipulator arm, and photographed *Challenger*.

Table 4–35. Hilat Characteristics

Launch Date/Range	June 27, 1983/Western Test Range
Date of Reentry	n/a
Launch Vehicle	Scout
NASA Role	Launch services for U.S. Air Force
Responsible (Lead) Center	n/a
Mission Objectives	Place the satellite in orbit to permit the achievement of Air Force objectives and satellite evaluation of certain propagation effects of disturbed plasmas on radar and communications systems
Instruments and Experiments	1. Beacon measured signal scintillation. 2. Magnetometer measured field-aligned currents. 3. Particle detector measured precipitating electrons in the 10,000–20,000 eV range. 4. Auroral/ionospheric mapper measured the visible and ultraviolet auroras. 5. Drift meter determined the electronic field from ion drift measurements.
Orbit Characteristics:	
Apogee (km)	819
Perigee (km)	754
Inclination (deg)	82
Period (min)	100.6
Weight (kg)	101.6
Dimensions	n/a
Shape	n/a
Power Source	Solar arrays
Prime Contractor	Applied Physics Laboratory, Johns Hopkins University

Table 4–36. Charge Composition Explorer Characteristics

Launch Date/Range	August 16, 1984/Cape Canaveral
Date of Reentry	Stopped transmitting data January 1989; was officially terminated July 14, 1989; has not reentered the atmosphere
Launch Vehicle	Delta 3924
NASA Role	Provided instrument for cooperative international mission; project management; launch services
Responsible (Lead) Center	Goddard Space Flight Center
Mission Objectives	Place the satellite in near-equatorial elliptical orbit to detect "tracer" ions released by the Ion Release Module within Earth's magnetosphere
Instruments and Experiments	1. Hot Plasma Composition Experiment monitored the natural low-energy magnetospheric tracer elements and detected artificially injected tracer ions at the Charge Composition Explorer over the low-energy range. 2. Charge-Energy-Mass Spectrometer measured the composition, charge state, and energy spectrum of the natural particle population of the ionosphere. 3. Medium Energy Particle Analyzer measured very small fluxes of lithium tracer ions over a wide energy range in the presence of the intense background of protons, alpha particles, and electrons while maintaining as large a geometry factor and as low an energy threshold as possible. 4. Magnetometer measured high-frequency magnetic fluctuations. 5. Plasma Wave Spectrometer provided first-order correlative information for studies of strong wave-particle interactions that develop close to the magnetic equator or have maximum effectiveness there. 6. Additional magnetic field and plasma ray experiments were conducted.
Orbit Characteristics:	
Apogee (km)	49,618
Perigee (km)	1,174
Inclination (deg.)	2.9
Period (min.)	939.5
Weight (kg)	242
Dimensions	122 cm across the flat sides and 40.6 cm high
Shape	Closed right octagonal prism
Power Source	Solar cell array, redundant nickel cadmium batteries, redundant battery charge controllers, and power switching and conditioning elements
Prime Contractor	Applied Physics Laboratory, Johns Hopkins University

Table 4–37. Ion Release Module Characteristics

Launch Date/Range	August 16, 1984/Cape Canaveral
Date of Reentry	November 1987
Launch Vehicle	Delta 3924
NASA Role	See Table 4–36
Responsible (Lead) Center	Goddard Space Flight Center; satellite provided by Federal Republic of Germany
Mission Objectives	Place the satellite in a highly elliptical orbit for the study of Earth's magnetosphere and release barium and lithium atoms into the solar wind and distant magnetosphere
Instruments and Experiments	1. Plasma Analyzer measured the complete three-dimensional energy-per-charge distributions of ions and electrons over the range of 10 V to 30 keV, as well as a retarding potential analyzer for the measurement of very low energy (~0 eV to 25 eV) electrons. 2. Mass Separating Ion Sensor measured simultaneously the distribution functions of ions of up to 10 different masses over an energy range of 0.01 to 12 keV/q. 3. Suprathermal Energy Ionic Charge Analyzer determined the ionic charge stage and mass composition of all major ions from hydrogen through iron over the energy range of 10–300 keV/q. 4. Magnetometer measured magnetic fields with a sensitivity of 0.1 nT. 5. Plasma Wave Spectrometer measured the intensities of the electric fields associated with plasma waves over the range of DC to 5 MHz with two long antennas and of magnetic wave fields from 30 Hz to 1 MHz with two boom-mounted search coils. 6. Lithium/Barium Release Experiments ejected 16 release canisters in pairs, eight with a Li-CuO mixture and eight with a Ba-CuO mixture, which ignited about a kilometer away from the spacecraft to expel hot lithium or barium gas.
Orbit Characteristics:	
Apogee (km)	113,818
Perigee (km)	402
Inclination (deg.)	27.0
Period (min.)	2,653.4
Weight (kg)	705 (including apogee kick motor)
Dimensions	Diameter of 1.8 m; height of 1.3 m
Shape	16 chemical release containers mounted on cylinder
Power Source	Solar array
Prime Contractor	Max Planck Institute for Extraterrestrial Physics under the sponsorship of the Research and Technology Ministry of the Federal Republic of Germany

Table 4–38. United Kingdom Subsatellite Characteristics

Launch Date/Range	August 16, 1984/Cape Canaveral
Date of Reentry	November 1988
Launch Vehicle	Delta 3924
NASA Role	See Table 4–36
Responsible (Lead) Center	Goddard Space Flight Center; satellite provided by Great Britain
Mission Objectives	Keep station with the IRM spacecraft at controllable distances of up to a few hundred miles to measure local disturbances created in the natural space plasma by the injection of tracer ions by the IRM
Instruments and Experiments	1. Ion Analyzer measured ion distribution over the energy range of 10 eV/q to 20 keV/q. 2. Electron Analyzer measured the electron distribution with high time and angular resolution over the energy range of 6 eV to 25 keV. 3. Particle Modulation Analyzer computed auto correlation functions and fast Fourier transform of electron and ion time variations resulting from wave-particle interactions and processed raw pulses from the electron and ion analyzers to reveal any significant resonances in the frequency range of 1 Hz to 1 MHz. 4. Magnetometer measured fields in the range of 0 to 256 nT or 0 to 9192 nT, with a resolution up to 30 pT, from DC to 10 Hz. 5. Plasma Wave Spectrometer measured the electric component of the plasma-wave field in the range of 10 Hz to 2 MHz and the magnetic component in the range of 30 Hz to 20 kHz.
Orbit Characteristics:	
Apogee (km)	113,417
Perigee (km)	1,002
Inclination (deg.)	26.9
Period (min.)	2,659.6
Weight (kg)	77
Dimensions	Diameter of 1 m, height of 0.45 m
Shape	Cylindrical
Power Source	Solar cells
Prime Contractor	Rutherford Appleton and the Mullard Space Science Laboratories under contract to the British Science and Engineering Research Council
Remarks	The satellite became inoperative after 5 months of operation. During that time, it had supported three chemical releases and had met 70 percent of the United Kingdom project objectives.

Table 4–39. Spartan 1 Characteristics

Launch Date/Range	June 17, 1985/Kennedy Space Center, deployed from Shuttle June 20
Date of Reentry	Retrieved June 24, 1985
Launch Vehicle	STS 51-G (*Discovery*)
NASA Role	Project management
Responsible (Lead) Center	Goddard Space Flight Center
Mission Objectives	Launch and retrieve Spartan 1, map the x-ray emissions from the Perseus Center, the nuclear region of the Milky Way galaxy, and the SCO X-2, and obtain engineering test data to prove the Spartan concept
Instruments and Experiments	The scanner observed various cosmic x-ray sources at rates of about 20 arc-sec/sec to provide x-ray data over an energy range of 0.5 keV to 15 keV. These observations were used for studies of emission processes in clusters of galaxies and the exploration of the galactic center.
Orbit Characteristics (same as Shuttle):	
Apogee (km)	391
Perigee (km)	355
Inclination (deg.)	28.5
Period (min.)	92
Weight (kg)	2,051
Dimensions	320 cm by 107 cm by 122 cm
Shape	Rectangular box
Power Source	Silver zinc batteries
Prime Contractor	Built by the Attached Shuttle Payloads Project at Goddard Space Flight Center

Table 4–40. Plasma Diagnostics Package Characteristics

Launch Date/Range	July 29, 1985
Date of Reentry	Retrieved July 29 after 6 hours of operation away from the orbiter; continued observations on-board orbiter throughout mission
Launch Vehicle	STS 51-F (*Challenger*)
NASA Role	Project management
Responsible (Lead) Center	Marshall Space Flight Center (Spacelab 2)
Mission Objectives	• Study orbiter-magneto plasma interactions in terms of density wakes, direct current electric fields, energized plasma, and a variety of possible wave-particle instabilities • Provide engine burns in support of the ground radar observations of the plasma depletion experiments for ionospheric and radio astronomical studies • Measure fields, waves, and plasma modifications induced by the orbiter and Spacelab subsystems in the payload bay and out to distances of 600 meters • Observe natural waves, fields, and plasmas in the unperturbed magnetosphere • Assess the Spacelab system performance of active and passive magnetospheric experiments • Develop the methods and hardware to operate instruments at the end of the remote manipulator arm and to eject and retrieve small scientific subsatellites
Instruments and Experiments	1. Quadrispherical low-energy proton and electron differential analyzer 2. Plasma wave analyzer 3. Electric dipole and magnetic search coil sensors 4. Direct current electric field meter 5. Triaxial flux-gate magnetometer 6. Langmuir probe 7. Retarding potential analyzer 8. Differential flux analyzer 9. Ion mass spectrometer 10. Cold cathode vacuum gauge
Orbit Characteristics:	
Apogee (km)	321
Perigee (km)	312
Inclination (deg.)	49.5
Period (min.)	90.9
Weight (kg)	407
Dimensions	Diameter of 106.9 cm; height of 140 cm to top of grapple fixture
Shape	Cylindrical with extendible antennas
Power Source	Battery
Principal Investigator	Dr. Louis A. Frank, University of Iowa

Table 4–41. Spartan 203 Characteristics

Launch Date/Range	January 28, 1986/Kennedy Space Center
Date of Reentry	None
Launch Vehicle	STS 51-L (*Challenger*)
NASA Role	Project management
Responsible (Lead) Center	Goddard Space Flight Center
Mission Objectives	Determine the composition of Comet Halley when it was under greatest heating and was, therefore, most active, and look for changes in the composition and structure of the comet as it drew closer to the Sun
Instruments and Experiments	Two ultraviolet spectrometers were to survey Comet Halley in ultraviolet light from 128 nm to 340 nm wavelength. The spectrometers were also to observe the comet close to the perihelion and to look for cometary composition constituents and their rates of change during this highly active period in the cometary life cycle.
Orbit Characteristics	Did not achieve orbit
Weight (kg)	2,041
Dimensions	Carrier: 132 cm by 109 cm by 130 cm
Shape	Rectangular box
Power Source	Silver zinc batteries
Prime Contractor	General Electric-Matsco, Physical Sciences Laboratory at the University of New Mexico
Remarks	Although the Spartan program would continue during the next decade, this opportunity to observe Comet Halley was lost.

Table 4–42. Polar BEAR Characteristics

Launch Date/Range	November 13, 1986/Western Test Range
Date of Reentry	n/a
Launch Vehicle	Scout
NASA Role	Launch services for U.S. Air Force
Responsible (Lead) Center	n/a
Mission Objectives	Place the Air Force P87-1 (Polar BEAR) satellite into an orbit that will enable the successful achievement of Air Force mission objectives
Payload Objectives	Conduct several experiments to study atmospheric effects on electromagnetic propagation
Instruments and Experiments	1. Geophysics experiment photographed the aurora borealis. 2. Defense Nuclear Agency beacon experiment measured distortion of the ionosphere.
Orbit Characteristics	
Apogee (km)	1,014
Perigee (km)	954
Inclination (deg)	89.6
Period (min.)	104.8
Weight (kg)	122.5
Dimensions	n/a
Shape	Cylindrical
Power Source	Solar arrays
Prime Contractor	Applied Physics Laboratory, Johns Hopkins University

Table 4–43. San Marco D/L Characteristics

Launch Date/Range	March 25, 1988/San Marco Equatorial Range in Kenya, Africa
Date of Reentry	December 6, 1988
Launch Vehicle	Scout (launch was conducted by an Italian crew)
NASA Role	Provided an ion velocity instrument, wind/temperature spectrometer, electric field instrument, and Scout launch vehicle for cooperative mission with Italy
Responsible (Lead) Center	NASA Headquarters Office of Space Science and Applications (OSSA) and Goddard Space Flight Center
Mission Objectives	Launch satellite into low-Earth orbit to explore the possible relationship between solar activity and meteorological phenomena and determine the solar influence on low atmosphere phenomena through the thermosphere by obtaining measurements of parameters necessary for the study of dynamic processes occurring in the troposphere, stratosphere, and thermosphere
Instruments and Experiments	1. Neutral Atmosphere Density Experiment (Italy) measured drag forces on the satellite in orbit. 2. Airglow Solar Spectrometer (West Germany) measured equatorial airglow, solar extreme ultraviolet radiation, solar radiation from Earth's surface and from clouds, and the radiation from interplanetary and intergalactic origins reaching the satellite. 3. Wind and Temperature Spectrometer (Goddard) measured neutral winds, neutral particle temperatures, and concentrations of selected gases in the atmosphere. 4. Three-Axis Electric Field Experiment (Goddard) measured the electric field surrounding the spacecraft in orbit. 5. Ion Velocity Instrument (University of Texas) measured the plasma concentration and ion winds surrounding the spacecraft in orbit.
Orbit Characteristics:	
Apogee (km)	614
Perigee (km)	260
Inclination (deg.)	2.9
Period (min.)	99
Weight (kg)	237
Dimensions	96.5 cm diameter
Shape	Spherical
Power Source	Solar cell array
Prime Contractor	Satellite was provided by Centro Ricerche Aerospaziali (Italy)
Remarks	The wind and temperature spectrometer instrumentation system failed after providing approximately 1 week of data. The remaining four experiments operated satisfactorily.

Table 4–44. Chronology of Spacelab Development

Date	Event
Sept. 10, 1971	First documented use of the term "Sortie Can," predecessor to Spacelab, is used. NASA Headquarters Space Station Task Force Director Douglas R. Lord asks Marshall Space Flight Center to begin an in-house design study of a Sortie Can, a manned system to be carried in the Shuttle cargo bay for the conduct of short-duration missions.
Nov. 30–Dec. 3, 1971	The Joint Technical Experts Group meets in Washington.
Feb. 16, 1972	NASA Associate Administrator for Manned Space Flight Dale Myers investigates the Sortie Can and related activities at Marshall and issues new guidelines.
June 14–16, 1972	A delegation from the European Space Conference travels to Washington for a discussion with senior U.S. officials. The European Research and Technology Center (ESTEC) is assigned the task of determining needed resources for Europe to develop the Sortie Module (Lab).
July 31–Aug. 4, 1972	NASA Associate Administrator for Space Science Dr. John E. Naugle heads a Space Shuttle Sortie Workshop at Goddard Space Flight Center.
Aug. 17–18, 1972	NASA Headquarters hosts a meeting to review provisions that might appear in an agency-to-agency agreement that was developed based on earlier agreements between Europe and NASA.
Nov. 8–9, 1972	European space ministers agree to formulate plan for a single European space agency by December that would merge the existing European Space Research Organization (ESRO) and European Launcher Development Organization (ELDO) into the European Space Agency (ESA).
Dec. 20, 1972	At the space ministers' official meeting, the formal development commitment to the Sortie Lab is made.
By Jan. 1973	NASA and Europeans prepare first drafts of an agency-level agreement.
Jan. 9, 1973	ESRO's format of a Memorandum of Understanding (MOU) is discussed by Roy Gibson, ESRO's deputy of administration, and Arnold Frutkin, NASA's Associate Administrator for International Affairs.
Jan. 15–17, 1973	A symposium is held at ESRO's European Space Research Institute (ESRIN) facility in Frascati, Italy, to acquaint European users with the Sortie Lab (Spacelab) concept.
Jan. 18, 1973	The ESRO Council meets and votes to authorize a "Special Project" to develop the Sortie Lab, which the Europeans call Spacelab.
Jan. 23, 1973	Frutkin receives revised MOU, prepared by ESRO.
Feb. 22–23, 1973	NASA and State Department representatives travel to Paris. Although the stated purpose of the meeting is to work on the agency-to-agency agreement, the U.S. team gets its first look at the intra-European agreement, then in draft form, which would firmly commit the European signers to Spacelab development.

Table 4–44 continued

Date	Event
March 23, 1973	The program directors approve the first Spacelab concept document, “Level I Guidelines and Constraints for Program Definition,” formulated by NASA. It addresses programmatics, systems, operations, interfaces, user requirements, safety, and resources.
May 1973	The expanded working groups review the findings from the July 1971 Goddard workshop, identify new requirements for the Shuttle and sortie systems, and identify systems and subsystems to be developed in each discipline. They also identify supporting research and technology needs, note changes in policies or procedures to fully exploit the Shuttle, and prepare cost, schedule, and priority rankings for early missions.
May 3–4, 1973	Representatives from Belgium, France, West Germany, Italy, the Netherlands, Spain, and the United Kingdom meet at the U.S. State Department to negotiate the draft intergovernmental agreement and the related draft NASA/ESRO MOU.
July 25, 1973	The Concept Verification Test (CVT) is assembled to simulate high-data-rate experiments emphasizing data compression techniques, including data interaction and on-board processing.
July 30, 1973	The Interim Programme Board for the European Spacelab Programme meets and approves the text of the intergovernmental agreement, the text of the MOU, and a draft budget.
July 31, 1973	The ministers of 11 European countries agree to a “package deal” by the European Space Conference.
Aug. 10, 1973	Belgium, France, West Germany, Switzerland, and the United Kingdom endorse the “Arrangement Between Certain Member States of the European Space Research Organization and the European Space Research Organization Concerning the Execution of the Spacelab Program.” Subsequently, Spain, the Netherlands, Denmark, Italy, and later Austria also sign the arrangement.
Aug. 14, 1973	Belgium, France, West Germany, Switzerland, the United Kingdom and the United States sign the intergovernmental agreement titled “Agreement Between the Government of the United States of America and Certain Governments, Members of the European Space Research Organization, for a Cooperative Program Concerning the Development, Procurement, and Use of a Space Laboratory, In Conjunction with the Space Shuttle System.” The Netherlands signs on August 18, Spain on September 18, Italy on September 20, and Denmark on September 21.

Table 4–44 continued

Date	Event
Aug. 15, 1973	This is the "magic" date when NASA would have to initiate the program, in the absence of a European undertaking, to have a Sortie Laboratory available for use by 1979. It states a readiness, therefore, to accept a firm European commitment in October and signed agreement by late October–early November, along with immediate initiation of a full-scale project definition effort, as well as an added proviso that the Europeans could withdraw from that commitment by August 15, 1973, if their definition work indicated that the projected target costs would be unacceptably exceeded.
Sept. 7, 1973	The NASA-developed Spacelab Design Requirements are reviewed and approved by NASA Administrator James Fletcher.
Sept. 21, 1973	The second issue of the Guidelines and Constraints Document is signed.
Sept. 24, 1973	In a U.S. Department of State ceremony in Washington, Acting Secretary of State Kenneth Rush and the Honorable Charles Hanin, Belgian science minister and chairman of the European Space Conference, sign a communiqué noting the completion of arrangements for European participation in the Space Shuttle program and marking the start of a new era in U.S.-European space cooperation. NASA Administrator James C. Fletcher and Dr. Alexander Hocker, director general of the ESRO, also sign the MOU to implement this international cooperative project.
Oct. 1973	The NASA Headquarters Sortie Lab Task Force is renamed the Spacelab Program Office, with responsibilities for overall program planning, direction, and evaluation as well as establishing program and technical liaison with ESRO. The name change from Sortie Lab to Spacelab recognizes the right of ESRO, as the sponsoring agency, to choose its preferred title for the program.
Oct. 9–10, 1973	Marshall reviews the preliminary design effort.
Nov. 16, 1973	NASA Administrator Fletcher directs NASA to evaluate the impact of a Shuttle docking module (then required on Shuttle missions carrying more than three crew members) on the mission model and on specific payloads.
Jan. 1974	The NASA administrator agrees with the recommendations not to use a docking module on all Spacelab missions. A general purpose laboratory, much like a Spacelab module, is added to the CVT complex at Marshall.
Early 1974	The Joint User Requirements Group begins informal discussions of the real Spacelab mission. The Joint Spacelab Working Group (JSWG) expresses its concern over the need to use the first missions to verify Spacelab performance.
March 5, 1974	The third version of the Guidelines and Constraints Document is signed and renamed the "Level I Programme Requirements Document."

Table 4–44 continued

Date	Event
March 19, 1974	The JSWG meets and establishes the Spacelab Operations Working Group with the thought that it would have a limited life, possibly through the Critical Design Review. In actuality, the Operations Working Group continues not only beyond that time, but eventually is divided into two groups, one focused on ground operations, the other on flight operations. The Software Coordination Group is also established; its initial focus is on the HAL-S and GOAL languages, which NASA is to furnish to ESRO, but it quickly broadens its scope to include microprogramming. Dr. Ortner of ESRO proposes a joint ESRO/NASA program called the Airborne Science/Spacelab Experiments System Simulation (ASSESS). By May, it is agreed that a joint mission could be authorized under the umbrella of the Spacelab MOU by a simple exchange of letters between the two program directors. The JSWG states that the Spacelab program should dictate the flight configuration and specify the resources available for experiments. It specifies that the first mission would have a long module and a pallet of two segments; 3,000–4,000 kg of weight, 1.5–2.5 kW of electrical power, and approximately 100–150 hours of crew time would be available for experiment activities; and the first mission would be no longer that 7 days.
April 23, 1974	The NASA/ESRO Joint Planning Group, co-chaired by Dr. Gerald Sharp of NASA and Jacques Collet of ESRO, meet to develop guidelines and procedures for selecting the first Spacelab payload.
May 17, 1974	NASA presents an expanded set of constraints for consideration at a JSWG meeting, including constraints imposed by the Shuttle, one of which is a limit of four to five crew members for the first Spacelab mission if it is conducted, as then planned, on the seventh Shuttle flight.
May 20, 1974	First annual review of the Spacelab program is held.
May 29–30, 1974	After it is suggested that the CVT general purpose laboratory be upgraded to make it more like the Spacelab design, a Preliminary Requirements Review for the improved simulator is held. Its completion is planned for mid-1976.
Summer of 1974	Some 60 Europeans, both ESRO and industry representatives of the Spacelab team, embark on a 2-week visit to the United States.
July 1–14, 1974	Fourteen points are approved by the NASA Manned Space Flight Management Council. The configuration now states a one- or two-segment pallet with the long module. Weight and power are unchanged, but the crew size is to be "minimized" and "up to" 100 crew-hours would be available for experiment operations.
July 12, 1974	John Thomas, NASA's chief engineer for the Spacelab Program Office at Marshall, gives the first detailed requirements of the Verification Flight Instrumentation to the JSWG. He presents parameters to be measured, the type of test equipment, power and weight requirements, and summary mission timelines.

Table 4–44 continued

Date	Event
July 15–19, 1974	An integrated life science mission is conducted in the CVT facility. Planned and conducted by Ames Research Center scientists, this test demonstrates candidate experiment protocols, modular organism housing units, and rack-mounted equipment plus radioisotope tracer techniques.
July 22–23, 1974	The Spacelab team visits Johnson Space Center for technical discussions of the primary Shuttle/Spacelab interfaces.
Aug. 8, 1974	A letter from Lord to Stoewer, the ESRO acting program director, projects a joint mission in 1975 to draw up Spacelab design conclusions, study operational concepts, and perform scientific experiments. Marshall issues an Instrument Pointing System (IPS) Requirements Document.
Aug. 26, 1974	Stoewer's confirmation letter states full agreement with Lord's proposal but cautions that ESRO's funding limit for the first mission is 350,000 accounting units (approximately $440,000 at the time). By the end of 1974, planning for the first ASSESS mission is to take shape. A series of five flights on consecutive days would approximate the useful time of a 7-day Spacelab mission.
Sept. 23, 1974	The Joint Planning Group meets. ESRO reports that a call for Spacelab utilization ideas elicited 241 replies, over half of which were new "customers" for space experimentation. The JSWG members discuss the constraints for the second Spacelab mission, the most important one being that it would not be a joint payload. ESRO does not agree to this point. NASA also suggests that a DOD mission might replace the first Spacelab on the first Shuttle operational flight. ESRO objects strongly to this proposal.
Sept. 26, 1974	The new version of the Programme Requirements Document (Revision 1) is signed.
Oct. 21–31, 1974	After receipt of the data package from ERNO on October 21, independent technical teams are set up by ESRO at ESTEC and by NASA at Marshall. The teams conduct their reviews and write Review Item Discrepancies (RIDs). The three baseline documents for this review are: the Program Requirements Document (Level I), the System Requirements Document (Level II), and the Shuttle Payload Accommodations, Volume XIV.
Nov. 7, 1974	The Shuttle/ Spacelab Interface Working Group on Avionics, or, as it is soon called, the Avionics Ad Hoc Group, is established by agreement of the program directors.
Dec. 1974	NASA accepts ESRO's choice of the Mitra 25 computer system.
Dec. 11, 1974	The Joint Planning Group holds its final meeting; its functions would be assumed by line payload organizations.
Jan. 1975	It is agreed that the transfer tunnel would be offset below the orbiter centerline so that lightweight payloads could be mounted on bridging structures above the tunnel if desired.

Table 4–44 continued

Date	Event
March 1975	A second decision establishes the approach to the orbiter end of the tunnel. The Shuttle program would build a removable tunnel adapter, which would be placed between the Spacelab tunnel and the orbiter cabin wall. The adapter would have doors at both ends and a third door at the top where the airlock could be mounted.
May 29–30, 1975	The NASA Preboard "N" chaired by Jack Lee conducts its review of the System Requirements Documents at Marshall. In the meantime, ESA conducts a parallel review.
June 4, 1975	An annual review of the Spacelab program is held. Roy Gibson, director of ESA, and NASA Administrator Fletcher propose to accept the objectives for the first Spacelab payload as presented by the Joint Planning Group, and the group formally dissolves. A review is also presented on the status of the IPS proposal.
June 7, 1975	The ASSESS simulation flights are conducted, successfully completing the program at Ames Research Center. The international crew of five completes a 6-day mission on board the CV 990 Galileo II.
June 9, 1975	The combined ESA/NASA teams meets in Noordwijk to consider the 1,772 RIDs prepared by both agencies.
Aug. 28–29, 1975	ESA Spacelab Programme Director Deloffre and Lord draft a "package deal" that would commit the agencies to develop or fund activities and equipment that have been in question.
Sept. 1975	By this meeting between Lord and Deloffre, plans for go-ahead have fallen apart. ESA has rejected the Dornier proposal (submitted through ERNO as the prime contractor) because of unacceptable schedule and cost risks. ESA has issued RFPs to ERNO, MBB, and Dornier, with a response due December 5.
Sept. 24, 1975	Revision 2 of the Programme Requirements Document is issued.
Sept. 30, 1975	The main contract between ESA and prime contractor VFW Fokker/ERNO is signed in the amount of approximately 600 million Deutschmarks. Over the next 9 months, negotiations between ERNO and its co-contractors are concluded.
Nov. 17–21, 1975	Another CVT simulation is conducted to determine how effectively a team of scientists in orbit, with only moderate experiment operations training, could conduct experiments while being monitored on the ground by principal investigators using two-way voice and downlink-TV contact.
Nov. 18–19, 1975	The Joint Program Integration Committee meets and reviews preliminary management plans for the first mission, Level I constraints, Level II guidelines imposed by the system and verification test requirements, and payload accommodation study results and plans.

Table 4–44 continued

Date	Event
Winter 1975–1976	The ESA team holds subsystem reviews. Also, ESA Spacelab Programme Director Bernard Deloffre works to sign contracts with each member of the consortium, reduce the backlog of engineering change proposals, recover schedule slips, and meet with European and NASA groups to review the program. To improve NASA's visibility into the European contractor effort, Deloffre invites NASA program management to participate in his quarterly reviews at ERNO beginning in September 1975.
By early 1976	ESA receives two proposals for the IPS: a joint bid on the IPS by Dornier and MBB and a bid from ERNO covering integration of the IPS into the Spacelab.
March 1976	Final approval is obtained to conduct ASSESS II as a joint mission sponsored by NASA's Office of Applications and Office of Space Flight and by ESA. The ESA Industrial Policy Committee authorizes Deloffre to proceed with the IPS contracts.
March 4–5, 1976	At the Joint Spacelab Working Group meeting, ESA reports that 110 engineering change proposals have been resolved with ERNO and only 90 are left open. The cost of the changes recently approved is 15 million accounting units (approximately $15 million at that time).
March 17, 1976	NASA's Fletcher, Low, Naugle, Mathews, Yardley, McConnell, Calio, Culbertson, Frutkin, and Lord deliberate the latest ESA proposal on the IPS. They agree to advise ESA that NASA would use an ESA IPS that meets the specification requirements and that NASA's first potential use would be on Spacelab 2.
March 19, 1976	Deloffre reports that his reserves on the program are down to only 5 million accounting units.
March–June 1976	ESA and NASA jointly conduct the Spacelab Requirements Assessment and Reduction Review. This review evaluates program needs and eliminates those items that have crept into the program but could be deleted with a considerable cost saving.
April 1976	ESA establishes a Software Audit Team to assess the software situation and make recommendations.
May 12, 1976	The Software Audit Team presents its preliminary findings to the ESA Spacelab Programme and project managers.
May 26, 1976	NASA (Marshall) issues an RFP for a Spacelab integration contract to secure a contractor to provide support in developing Spacelab hardware that is NASA's responsibility and analytical and hands-on support in the integration and checkout of Spacelab hardware during the system's operational lifetime.
June 2, 1976	The Software Audit Team makes its final presentation to ESA, ERNO, and co-contractors. The group concludes that Spacelab software is not in good shape and that there does not seem to be a structure for improving the situation.

Table 4–44 continued

Date	Event
June 16, 1976	The third annual meeting of the agency heads (Gibson and Fletcher) occurs in Washington, D.C. Discussed is the claim that the logistics requirements have been almost totally neglected in the agreements and contracts to date. Fletcher signs a letter to Gibson concurring with ESA's plans to proceed with IPS development. Fletcher urges that the delivery schedule provide adequate time for integration of payloads and checkout of the combined system for the planned launch date in 1980.
June 18, 1976	A NASA Program Director's Review is held, and Luther Powell of the Marshall project team summarizes activities in support of Preliminary Design Review-A (PDR-A).
June 24–25, 1976	The technical experts team analyzes its planned reviews with ESA at ESTEC and goes to Bremen for the final reviews between ESA and ERNO. By the time the senior NASA representatives arrive on July 1–2, chaos is reigning. PDR-A is a complete disaster. Documentation is inadequate, schedules are slipping, the budget cannot be held, the contractor team is out of control, and the team morale is at an all-time low.
June 28, 1976	NASA distributes the data packages for the Preliminary Operations Requirements Review for ground operations. The purpose of this review is to obtain agreement on ground operations requirements, including integration at Level I, II, and III, logistics, training of ground processing personnel, ground support equipment, facilities, contamination control, and safety.
July 7, 1976	Gibson signs a PDR implementation plan with Hans Hoffman at ERNO for a simple and straightforward approach to PDR-B.
July 15, 1976	A final CVT simulation to employ a high-energy cosmic ray balloon flight experiment is conducted.
July 30, 1976	Further changes are approved to the Programme Requirements Document. The most important ones note the addition of NASA-furnished utility connectors (from the orbiter to Spacelab) and a trace gas analyzer.
Aug. 1976	At the Program Director's Review, John Waters of Johnson Space Center presents a plan to procure a simulator to operate alone or with the Shuttle Mission Simulator and the Mission Control Center at Houston to produce a high-fidelity mission simulation.
Sept. 18, 1976	Gibson and Fletcher meet at Ames Research Center to tackle Spacelab logistics.
Nov. 1, 1976	ESA selects Michel Bignier as director of the Spacelab Programme.
Early Nov. 1976	Bignier and Gibson recognize that Spacelab funding is out of hand and propose descoping the program.
Nov. 22–23, 1976	NASA astronauts Paul Weitz, Ed Gibson, Bill Lenoir, and Joe Kerwin conduct a walkthrough of the Spacelab module at ERNO. They simulate various airlock operations and note further improvements needed.
Dec. 4 and 8, 1976	ESA, ERNO, and NASA hold board meetings, resulting in agreement that PDR-B represents a major turnaround in the program.

Table 4–44 continued

Date	Event
Jan. 14, 1977	NASA Spacelab Deputy Director Jim Harrington states that ESA proposals could save as much as $84 million in the ESA budget but could impose on NASA an additional funding requirement of $26 million to $33 million. Fletcher and Gibson agree on the descoping items for ESA to go to its Spacelab Programme Board for approval.
Jan. 20–24, 1977	Gibson receives approval from the Spacelab Programme Board for all the proposed changes, with one notable exception. The board refuses to accept deletion of the IPS and decides instead to postpone decisions on this part of the program.
Feb. 23, 1977	The Spacelab module, which is produced by the Italian firm Aeritalia, successfully completes a series of limit, proof, and ultimate pressure testing.
March 1977	After many discussions and studies of various options, the NASA administrator decides to proceed with the development of a "hybrid" pallet to be used on several Shuttle orbital flight test (OFT) missions and that would also be available if the Spacelab system is delayed.
March 9, 1977	NASA announces the selection of McDonnell Douglas for the integration effort.
March 16, 1977	The ESA Spacelab Programme Board decides not to cancel the IPS as part of the overall program descoping.
April 1977	ESA Headquarters submits a proposal for a Spacelab Utilization Programme to its managing council. The report addresses three alternative programs for European use of the Spacelab.
April 25–29, 1977	The first formal Crew Station Review is held at ERNO and includes NASA astronauts Bob Parker, Paul Weitz, and Ed Gibson. Working with NASA, ESA, and ERNO specialists in crew habitability, they review the Spacelab design.
May 2, 1977	Bignier writes to Lord that only three engineering model pallets would be flightworthy, the others having been used in the test program in such a manner that they cannot be flown. NASA initially requested four pallets that could be flightworthy for OFT missions.
May 3–4, 1977	The JSWG meets, and Jim Harrington presents a NASA proposal for six preliminary options to meet the NASA requirement of having four pallets for the OFT missions.
May 16, 1977	"Launch" of the ASSESS II occurs. This mission emphasizes the development and exercise of management techniques planned for Spacelab using management participants from NASA and ESA who would be responsible for the Spacelab 1 mission, then scheduled for 1980.
May 30– June 5, 1977	John Yardley, the NASA associate administrator for space flight, visits Hawker-Siddeley Dynamics, ERNO, and Aeritalia to review the status of the program and progress on hardware fabrication.
June 1977	Co-contractor Critical Design Reviews (CCDRs) are held for electrical and mechanical ground support equipment.

Table 4–44 continued

Date	Event
June 16, 1977	ESA signs a fixed-price contract with Dornier for developing the IPS, with a delivery date of June 18, 1980. Dornier would be solely responsible for managing the IPS/Spacelab interface with no subcontract for this function.
June 20– July 12, 1977	The Preliminary Requirements Review for the transfer tunnel, which provides crew access to the module from the orbiter, is conducted.
July 1977	CCDRs are held for the data management subsystem and module structure. The first Electrical System Integration activity, the T800 self-test, is successfully completed. A Preliminary Requirements Review of the transfer tunnel is held, and the design and development of critical elements are initiated.
Aug. 1–19, 1977	A Preliminary Requirements Review for the Verification Flight Instrumentation is conducted.
Sept. 1977	CCDRs are held for crew habitability, system activation and monitoring, thermal control, and electrical power distribution systems. Testing is completed on the command and data management subsystem portion of the Electrical System Integration.
Oct. 1977	NASA drops its idea of using a hybrid pallet as a Spacelab backup.
Oct. 7, 1977	After touring several European government and industry facilities, new NASA Administrator Dr. Robert Frosch meets with Gibson in Paris. The target dates for Spacelabs 1 and 2 are now December 1980 and April 1981, respectively.
Nov. 1977	Reviews are conducted on the life support system, the igloo structure, and the airlock. A subsystem interface compatibility test is also completed.
Nov. 15–16, 1977	ESA expresses concern about the Spacelab reimbursement policy, particularly the high costs, and that ESA is not given preferential treatment by NASA in view of its development role.
Late 1977	The Spacelab payload planners, reacting to experiment proposals for the second mission, recommend a change in Spacelab 2 to fly a large cosmic ray experiment that could use its own independent structural mount to the orbiter.
Dec. 1977	A compatibility test between the command and data management subsystem and the first set of electrical ground support equipment, newly arrived from BTM, is completed. The IPS Preliminary Design Review is held. Concurrent reviews are held at Marshall and ESTEC; the final phase is held at Dornier. Results are encouraging, except for two discrepancies: certain structural elements are found to be made of materials susceptible to stress corrosion, and IPS software requirements needs better definition.
Jan. 23– March 10, 1978	The Software Requirements Review is conducted to define the operational software for the Spacelab flight subsystems and the ground checkout computers. ESA, NASA, and ERNO reach a technical agreement for the first time.

Table 4–44 continued

Date	Event
Jan. 30, 1978	After evaluation of the Spacelab Simulator by Johnson Space Center, a formal contract agreement is signed, and development begins with ERNO to provide the scientific airlock mockup for the simulator and data support to Link.
Feb. 1978	Another Crew Station Review allows the astronauts to review the scientific airlock hardware at Fokker and the improvements to the module at ERNO. Senior NASA and ESA officials meet to discuss the trade of one Spacelab for NASA launch services for European Spacelab missions. The results of this meeting are so encouraging that NASA terminates work related solely to contractual procurement in favor of concentrating on a barter agreement.
Feb. 7–8, 1978	The NASA preboard meets, and the focus is shifted to ESTEC for the joint team meetings starting on February 17.
Feb. 27, 1978	The final phase of the Critical Design Review begins in Bremen.
March 9, 1978	A draft MOU of the barter arrangement is reviewed by NASA and ESA representatives.
May 1978	Information on the planned mounting structure of the new Spacelab 2 configuration is submitted to ESA.
May 8, 1978	NASA administrator Frosch and ESA director general Gibson exchange letters that agree on a set of guidelines and a timetable leading to signature of the MOU to formalize the barter by the end of 1978.
May 16, 1978	ESA sends an RFP to ERNO for a firm evaluation of the cost of the second Spacelab flight unit. A separate request is sent to Dornier for a similar proposal on a second IPS.
June 1978	ESA Project Manager Pfeiffer reports that Electrical System Integration testing has been completed. T004, an assembly test involving the racks and floors of the engineering model of the Spacelab, is completed. McDonnell Douglas reports that it is having problems in both the design and fabrication for the flexible transfer tunnel sections. The Preliminary Design Review for the Verification Flight Instrumentation is completed, but it is not until July and November 1979 that a two-part Critical Design Review is completed for the Verification Flight Instrumentation for Spacelab 1.
June 12–13, 1978	The JSWG reports on user needs for more power, heat rejection, energy, data handling, and a smaller and lighter IPS. Bignier accepts the proposed changes to the Spacelab 2 configuration during the JSWG meeting.
July–Aug. 1978	A Critical Design Review for the OFT pallet system is conducted.
Aug. 1978	NASA and ESA announce the first selection of potential crew members for the early Spacelab missions. Drs. Owen K. Garriott and Robert A.R. Parker are named as mission specialists for the first Spacelab mission.

Table 4–44 continued

Date	Event
Aug. 8, 1978	ESA and NASA introduce their final candidates for the single payload specialist to be provided by each side. ESA has selected Dr. Wubbo Ockels, a Dutch physicist; Dr. Ulf Merbold, a German materials specialist; and Dr. Claude Nicollier, a Swiss astronomer. NASA has selected Byron K. Lichtenberg, a doctoral candidate in bioengineering at MIT, and Dr. Michael Lampton, a physicist at the University of California at Berkeley.
Sept. 14, 1978	A NASA delegation headed by John Yardley and Arnold Frutkin meets with the ESA Spacelab Programme Board to propose the mechanism for NASA to obtain the second Spacelab flight unit in exchange for Shuttle launch services.
Oct. 1978	The newly developed flexible multiplexer/demultiplexer (from the orbiter program) is accepted from Sperry, and the first OFT pallet structure is accepted at British Aerospace.
Oct. 7, 1978	Frosch and Gibson meet for a formal review of the overall Spacelab program. The meeting results in assignments to the Spacelab program directors to prepare a post-delivery change control plan, review an ESA proposal for operational support, and continue the analysis of European source spares. The Spacelab 1 mission is now targeted for June 1981 and Spacelab 2 for December 1981.
Oct. 10–11, 1978	European news media representatives attend a 2-day symposium at ERNO sponsored by the West German minister of research and technology, Volker Hauff. His opening remarks strongly endorse space efforts, Spacelab in particular, and issue an equally strong challenge to demonstrate the payoff for space activities.
Oct. 16 and 27, 1978	ERNO and Dornier submit their proposals for a procurement contract for the second Spacelab. ESA and NASA begin their evaluations.
Oct. 30, 1978	ERNO proposes a new schedule to ESA, which forecasts delivery of the engineering model to NASA in April 1980 and delivery of the flight unit in two installments: July and November 1980.
Nov. 13, 1978	A NASA team joins its ESA counterpart in Europe with the goal to define a procurement contract as early as possible in 1979.
Dec. 4, 1978	The OFT pallet arrives at Kennedy Space Center.
Jan. 1979	The oft-postponed module subsystems test is finally completed.
	NASA Administrator Frosch formally announces that NASA would proceed with both a free-flying 25-kW power module and an orbiter-attached power extension package to provide up to 15 kW power for a maximum of 20 days. Colin Jones presents a detailed progress review of the IPS to the JSWG. The delivery to Kennedy is now projected for July 1981.
Jan. 16, 1979	NASA applies to the Bureau of Customs of the Treasury Department for duty-free entry of the Spacelab from Europe under the Educational, Scientific, and Cultural Materials Importation Act of 1966.

Table 4–44 continued

Date	Event
March 12, 1979	Bignier and Lord attend the program review at Dornier and observe progress in the assembly and testing of all major hardware elements.
March 29, 1979	A meeting between Frosch and Gibson is held, and NASA proposes the formation of a joint ESA/NASA working group to define the follow-on development program.
By April 1979	Good progress is finally reported in the development of the flexible toroidal sections to be placed at each end of the transfer tunnel, which would minimize the transfer of loads between the tunnel and its adjoining structural elements. The development test program of the tunnel "flex unit" is successfully completed. Two sets of tests have been completed in at Johnson Space Center using European-supplied development components from the Spacelab data system.
May 1979	Preliminary Design Review activities previously terminated because of flex unit development problems are resumed and satisfactorily completed.
June 1979	A System Compatibility Review is held to verify the IPS design qualifications on the basis of testing already performed.
July 4, 1979	NASA and ESA agree to a letter contract for the procurement of essential long-lead items necessary for producing a second Spacelab.
Sept. 1979	The total hardware system of the simulator is shipped to Johnson Space Center and accepted. This includes the crew station, an instructor operator station from which training operations would be controlled, and supporting computer equipment.
Sept. 12, 1979	Bignier writes to Lord expressing serious concern over the escalation of cost of the vertical access kit, then under design review at SENER.
By Oct. 1979	The ESA Spacelab Programme Board indicates its reluctance to approve additional funding for Spacelab improvements in light of cost overruns in the current development program.
Nov. 1979	A two-part Critical Design Review is completed for the Verification Flight Instrumentation for Spacelab 1. MDTSCO has the complete Software Development Facility operational at the IBM Huntsville, Alabama, complex. The facility provides a duplication of the Spacelab system and simulates all the orbiter interfaces and also can model the experiments that would fly on Spacelab. Both pallets are ready for Level IV integration of the payload.
Late 1979	During the NASA administrator's review of the 1981 Office of Space Science budget, the consolidated Spacelab utilization costs raise serious concern about their magnitude. In particular, the administrator states that the costs are not in keeping with the concept of a walk-on laboratory. He calls for formation of a Spacelab Utilization Review Committee to analyze the costs and to make recommendations for making the Spacelab a cost-effective vehicle for science missions. The pallet for the OSS-1 payload is transported from Kennedy to Goddard over the road, using the Payload Environmental Transportation System.

Table 4–44 continued

Date	Event
Jan. 1980	A contract is signed by Marshall (as the procurement agent for NASA) and ESA to purchase the second flight unit at a cost of approximately $184 million. The first assembly test of the racks, floor, and subfloor of the flight unit is completed, a full 2 weeks ahead of the new schedule.
Feb. 1980	Work starts on the long module integration test of the engineering model. Jesse Moore proposes to Lord to modify the Spacelab 2 configuration again to change from a three-pallet train with igloo to a single pallet with igloo plus a two-pallet train. This is accepted as the new configuration for Spacelab 2 unless later loads analyses show the need for further changes.
Feb. 14, 1980	Agency heads meet to review the Spacelab program in Paris. It is noted that, despite considerable progress by both ESA and NASA, the date for the first Spacelab flight has slipped to December 1982.
April 1980	Part I of the Engineering Model Acceptance Review is held. Nine teams evaluated a major portion of the deliverable acceptance data package and some 800 discrepancy notices are written.
Late May 1980	ESA and NASA sign an agreement for procurement of a second IPS for approximately $20 million, scheduled for delivery in the fourth quarter of 1983.
July 1980	The second major test of the flight unit is completed, although special test equipment has to be used to replace a faulty diverter valve.
Oct. 1980	The October monthly program report from ESA and NASA states that the engineering model and flight unit test (including electromagnetic compatibility) was completed on October 1, and with that test, the engineering model system integration program is completed.
Oct. 20, 1980	The Engineering Model Test Review Board gives final approval for full disassembly of the engineering model.
Nov. 4, 1980	The Engineering Model Test Review Board gives final approval for the start of the formal acceptance review, also known as the Engineering Model Acceptance Review Part II.
Nov. 24–25, 1980	The Engineering Model Acceptance Review Part II is successfully completed, with the final board giving permission to ship the hardware to Kennedy.
Nov. 28, 1980	The final segment of the engineering model is rolled out of the ERNO Integration Hall and is transported to Kennedy in three major shipments.
Late 1980	The first pallet is moved to the cargo integration test equipment stand to prepare for a simulated integration with the orbiter.
Dec. 5, 1980	The first shipment of the engineering model is brought to Kennedy on a C5A airplane. It contains the core segment, one pallet, and miscellaneous electrical ground support equipment (EGSE) and mechanical ground support equipment (MGSE), with a total weight of 29.9 metric tons.

Table 4–44 continued

Date	Event
Dec. 8, 1980	The second shipment of the engineering model arrives at Kennedy via a Lufthansa 747 airplane containing two pallets, miscellaneous EGSE and MGSE, and documentation, with a total weight of 36.3 metric tons.
Dec. 13, 1980	The third shipment of the engineering model arrives at Kennedy via a C5A plane containing the experiment segment, two pallets, and miscellaneous EGSE and MGSE, with a total weight of 33.6 metric tons.
Mid-Dec. 1980	The flight unit racks are accepted by NASA and delivered to the SPICE facility in Porz-Wahn.
March 4, 1981	A symbolic turnover of OSTA-1 from Rockwell to Johnson is accomplished.
March 10, 1981	A second turnover of OSTA-1 to Kennedy takes place.
April 8, 1981	ESA project manager Pfeiffer writes to John Thomas, the new NASA Spacelab program manager at Marshall, advising him of the April 3 selection of a new design concept for the IPS. ESA concludes that the existing mechanical design would have failed at several critical sections from the structural loads. The basic electronics concept, however, would be retained.
June 1981	The first part of the Flight Unit 1 Acceptance Review covering EGSE servicers, flight software, and spares is successfully completed. (Flight Unit 1 contains the module.)
June 15, 1981	The modified igloo is returned to ERNO for SABCA, and, after small modifications are made to the igloo support structure, work begins on integrating Flight Unit 2 (which contains the igloo).
June 26, 1981	The quarterly progress meeting at Dornier is held. Dornier presents the details of its new design concept and the results of recent hardware testing. Jim Harrington, NASA program director, summarizes the successful first flight of the Space Shuttle.
July 27, 1981	The first set of Flight Unit 1 hardware is shipped to Kennedy.
July 1981	Dornier's redesign concept of the IPS is given a go-ahead. The first set of EGSE is received by Kennedy. Following the successful completion of the tests in the cargo integration test equipment stand, a payload Certification Review certifies that OSTA-1 is prepared to support the STS-2 Flight Readiness Review and that the integrated payload and carrier are ready for testing with the orbiter. This affirms the operational readiness of the supporting elements of the mission.
Aug. 31, 1981	The report from Pfeiffer states that there are no outstanding technical problems in the first part of Flight Unit 1.
Sept. 1981	A new Preliminary Design Review is held of the IPS.
Nov. 4, 1981	Orbiter processing proceeds normally; the second Shuttle launch occurs. OSTA-1 provides abundant data. From the Spacelab viewpoint, OSTA-1 demonstrates the outstanding performance of the pallet for carrying experiments.

Table 4–44 continued

Date	Event
Nov. 30, 1981	The second part of the Flight Unit 1 Acceptance Review is completed, with the board's decision to approve Flight Unit 1 for shipment to Kennedy. A formal Certificate of Acceptance is signed by the program directors, project managers, and acceptance managers for the two agencies and for the prime contractor.
Dec. 7, 1981	Testing resumes 3 weeks late on the Flight Unit 2 systems.
Dec. 8, 1981	The OFT Pallet Program Manager's Review is conducted at Marshall.
Dec. 15, 1981	The OSS-1 Pallet Pre-Integration Review is conducted at Marshall.
Jan. 1982	A Spacelab 2 Interface Review is held of the IPS. By early 1982, the entire transfer tunnel assemblage is delivered to Kennedy, ready for processing for the first Spacelab mission.
Jan. 5, 1982	The Cargo Readiness Review of the OSS-1 Pallet is held at Kennedy.
Jan. 26–28, 1982	An OSS-1 simulation is conducted at Johnson.
Feb. 1982	The engineering model is powered up to begin tests simulating those to be conducted later with the first flight unit.
March 9, 1982	The Flight Readiness Review for OSS-1 is completed.
March 22, 1982	STS-3 is launched on its successful 7-day mission with the OSS-1 payload in the cargo bay.
March–Oct. 1982	It is agreed that NASA would conduct a Design Certification Review with support from ESA and its prime contractor ERNO to: review the performance and design requirements; determine that design configurations satisfied the requirements; review substantiating data verifying that the requirements had been met; review the major problems encountered during design, manufacturing, and verification and the corrective action taken; and establish the remaining effort necessary to certify flightworthiness.
June 10, 1982	Spacelab 1 faces its first operational review, the Cargo Integration Review for the STS-9 mission, conducted at Johnson. The board concludes that the hardware, software, flight documentation, and flight activities would support the planned launch schedule of September 30, 1983.
June 17, 1982	Agency heads meet in Paris. James E. Beggs has replaced Dr. Frosch as NASA administrator.
July 3, 1982	The final Flight Unit Acceptance Review for Flight Unit 2 is completed with the board meeting.
By July 7, 1982	A new cost review is presented to the administrator by Mike Sander and Jim Harrington. Their presentation focuses on three areas of Spacelab costs: operations, mission management, and instrument development.
July 8, 1982	The second Certificate of Acceptance is signed for Flight Unit 2.
July 29, 1982	The final shipment of large components of Flight Unit 2 is delivered to Kennedy from Hanover. It contains the igloo and the final three pallets, carried by C5A.
Aug. 1982	A Critical Design Review of the redesign of the IPS is held.

Table 4–44 continued

Date	Event
Dec. 6–9, 1982	The Johnson Mission Integration Office under Leonard Nicholson conducts an STS-9 Integration Hardware/Software Review to verify the compatibility of the integrating hardware and software design and orbiter capability against the cargo requirements for STS-9. The overall findings verify that the orbiter payload accommodations would meet the cargo requirements and can support the STS-9 launch schedule
Jan. 13, 1983	The final presentations and NASA Headquarters board review of the Design Certification Review are held.
Jan.–March 1983	The Spacelab 1 system test is conducted, verifying the internal interfaces between the subsystem and the experiment train, including the pallet.
March and April 1983	The experiments are powered up and total system verified in a mission sequence test simulating about 79 hours of the planned 215-hour flight, with the orbiter simulated by ground support equipment and the high-data-rate recording and playback demonstrated.
April 1983	A Design Certification Review on the verification flight tests and Verification Flight Instrumentation is completed.
May 1983	Subsystem integration of the new IPS system begins. The transfer tunnel is integrated to the module and its interfaces verified.
May 17, 1983	The NASA administrator signs a blanket certificate for the duty-free entry of Spacelab and Remote Manipulator System materials.
May 18, 1983	Spacelab is moved to the cargo integration test equipment stand for a higher fidelity simulation of the orbiter interface and use of the Kennedy launch processing system. During this test, the data link to the Payload Operations Control Center is simulated using a domestic satellite in place of the Tracking and Data Relay Satellite System. The cargo integration test equipment test is problem free.
June 17, 1983	Glynn Lunney, manager of the National Space Transportation System program at Johnson, issues the plan for the STS-9 Flight Operations Review to baseline the operations documentation through this management evaluation of the transportation of payload requirements into implementation plans and activities.
June 30, 1983	Lunney chairs the Flight Operations Board meeting at Johnson. The meeting includes a “walkthrough” of the STS-9 flight operations.

Table 4–44 continued

Date	Event
July 25, 1983	John Neilon, manager of NASA's cargo projects office, chairs a meeting of the Cargo Readiness Review Board. The review verifies the readiness of Spacelab 1 and supporting elements for on-line integration with the orbiter, verifies the readiness of the orbiter to receive Spacelab 1, and reviews the Kennedy cargo integration assessment from cargo transfer to the orbiter through mission completion, including identification of any major problems, constraints, or workarounds. The milestone events in the Spacelab program are reviewed, and all objectives are accomplished in three key tests at Kennedy: the integrated systems test, the cargo/orbiter interface test, and the closed loop test from Spacelab to the Mission Control Center and Payload Operations Control Center
Aug. 15, 1983	Spacelab is placed in the payload canister, transferred to the Orbiter Processing Facility, and installed in the orbiter *Columbia*. Three tests are conducted during the next month: the Spacelab/orbiter interface test verifies power, signal, computer-to-computer, hardware/software, and fluid/gas interfaces; the Spacelab/tunnel/orbiter interface test verifies tunnel lighting, air flow, and Verification Flight Instrumentation sensors; and the end-to-end command/data link test verifies the Spacelab/orbiter/Tracking and Data Relay Satellite System/White Sands/Domat/Johnson/Goddard link.
Sept. 23, 1983	The orbiter is moved to the Vehicle Assembly Building.
Sept. 28, 1983	The Shuttle assembly is rolled out to the launch pad, with launch scheduled for September 30.
Sept. 29, 1983	The Shuttle assembly returns to the Vehicle Assembly Building because of a suspect exhaust nozzle on the right solid rocket booster.
Nov. 4, 1983	The orbiter is moved to the Vehicle Assembly Building for a second time.
Nov. 8, 1983	The Shuttle is rolled out again to the pad.
Nov. 28, 1983	Spacelab 1 flies on Shuttle mission STS-9.

Source: Douglas R. Lord, *Spacelab—An International Success Story*, NASA Scientific and Technical Division, NASA, Washington, DC, 1987.

Table 4–45. Spacelab 1 Experiments

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Solidification of Immiscible Alloys, 1ES301	H. Ahlborn, Federal Republic of Germany	Materials Science and Technology	Study alloys immiscible on Earth in a near-zero gravity environment to provide knowledge that may apply to industrial processes on Earth	Yes (Y)	100% of the planned objectives were accomplished using the isothermal heating furnace in the Materials Science Double Rack (MSDR).
Solidification of Technical Alloys, 1ES302	D. Poetschke, Federal Republic of Germany	Materials Science and Technology	Study technical alloys and the solidification process in near-zero gravity to provide knowledge that may apply to industrial processes on Earth	No (N)	This experiment was not performed in orbit because of the isothermal heating facility failure.
Skin Technology, 1ES303	H. Sprenger, Federal Republic of Germany	Materials Science and Technology	Study the casting of metals and composites in a near-zero gravity environment to provide knowledge which may apply to industrial processes on Earth	N	This experiment was not performed in orbit because of the isothermal heating facility failure.
Vacuum Brazing, 1ES304	E. Siegfried, Federal Republic of Germany	Materials Science and Technology	Study vacuum brazing in near-zero gravity to provide knowledge that may apply to industrial processes on Earth	Y	100% of the planned objectives were accomplished using the isothermal heating furnace in the MSDR.
Vacuum Brazing, 1ES305	R. Stickler, Austria	Materials Science and Technology	Study vacuum brazing in near-zero gravity to provide knowledge that may apply to industrial processes on Earth	Y	100% of the planned objectives were accomplished using the isothermal heating furnace in the MSDR.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Emulsions and Dispersion Alloys, 1ES306	H. Ahlborn, Federal Republic of Germany	Materials Science and Technology	Study the influence of surface tension on the separation process in immiscible alloys in a near-zero gravity environment to provide knowledge that may apply to industrial processes on Earth	Y	100% of the planned objectives were accomplished using the isothermal furnace in the MSDR. Fourteen samples of zinc-lead-bismuth alloys were processed.
Reaction Kinetics in Glass, 1ES307	H.G. Frischat, Federal Republic of Germany	Materials Science and Technology	Study reaction kinetics of glass in near-zero gravity to provide knowledge that may apply to industrial processes on Earth	N	This experiment was not performed in orbit because of the isothermal heating facility failure.
Metallic Emulsions of Aluminum-Lead, 1ES309	P.D. Caton, United Kingdom	Materials Science and Technology	Investigate stability and properties, effects of cooling rates, and alloy composition on particle size and distribution in an aluminum-lead system in near-zero gravity to provide new knowledge that may be applied to industrial processes on Earth	Partial (P)	Approximately 25% of the planned objectives were accomplished. The objectives not accomplished were attributed to the isothermal heating furnace failure.
Bubble Reinforced Materials, 1ES311	P. Gondi, Italy	Materials Science and Technology	Study bubble-reinforced materials in a near-zero gravity environment to provide knowledge that may apply to industrial processes on Earth	Y	100% of the planned objectives were accomplished using the isothermal heating furnace in the MSDR.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Nucleation Behavior of Silver-Germanium, 1ES312	Y. Malmejac, France	Materials Science and Technology	Study the nucleation behavior of silver-germanium in a near-zero gravity environment to provide knowledge that may apply to industrial processes on Earth	P	Approximately 33% of the planned objectives were accomplished. The objectives not accomplished were attributed to the isothermal heating furnace failure.
Solidification of Near Monotetic Zinc-Lead Alloys, 1ES313	H. Fischmeister, Austria	Materials Science and Technology	Study the lead content, size and distribution of lead particles, temperature and time of the solidification process, and structure of immiscible zinc-lead alloys in a near-zero gravity environment to provide knowledge that may apply to industrial processes on Earth	Y	100% of the planned objectives were accomplished using the isothermal heating furnace in the MSDR.
Dendrite Growth and Microsegregation, 1ES314	H. Fredriksson, Sweden	Materials Science and Technology	Study dendrite growth in near-zero gravity to provide knowledge that may apply to industrial processes on Earth.	Y	100% of the planned objectives were accomplished using the isothermal heating furnace in the MSDR.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Composites with Short Fibers and Particles, 1ES315	A. Deruyttere, Belgium	Materials Science and Technology	Melt and allow solidification of various metallic composites to investigate the casting process in a near-zero gravity environment and to study the behavior of solid particles dispersed in a liquid metal	P	Approximately 50% of the planned objectives were accomplished. The objectives not accomplished were attributed to the isothermal heating furnace failure. Several different aluminum and copper composites were used. Resultant enhanced bonding characteristics were observed because of the near-zero gravity environment.
Unidirectional Solidification of Aluminum-Zinc Emulsions, 1ES316	C. Potard, France	Materials Science and Technology	Study the homogenous distribution of aluminum-zinc emulsions and the solidification process in space to determine the structural properties of the solidified alloy	Y	100% of the planned objectives were accomplished in the low-temperature gradient furnace in the MSDR.
Unidirectional Solidification of Aluminum-Aluminum II Copper, and Silver-Germanium Eutectics, 1ES317	Y. Malmejac, France	Materials Science and Technology	Study the homogenous distribution of aluminum-aluminum II copper and silver germanium eutectics and the solidification process in space to determine the structural properties of the solidified alloy	Y	100% of the planned objectives were accomplished in the low-temperature gradient furnace in the MSDR.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Growth of Lead Telluride, 1ES318	H. Rodot, France	Materials Science and Technology	Study the homogenous distribution of lead telluride and the solidification process in space to determine the structural properties of the solidified alloy	Y	100% of the planned objectives were accomplished in the low-temperature gradient furnace in the MSDR.
Unidirectional Solidification of Eutectics, 1ES319	K.L. Muller, Federal Republic of Germany	Materials Science and Technology	Study the growth and distribution of tellurium, doped indium antimonide, and nickel antimonide alloy in a near-zero gravity environment	Y	100% of the planned objectives were accomplished in the low-temperature gradient furnace in the MSDR.
Thermodiffusion in Tin Alloys, 1ES320	Y. Malmejac, France	Materials Science and Technology	Study the homogenous distribution of tin alloys and the solidification process in space to determine the structural properties	Y	100% of the planned objectives were accomplished in the low-temperature gradient furnace in the MSDR.
Zone Crystallization of Silicon, 1ES321	R. Nitsche, Federal Republic of Germany	Materials Science and Technology	Study the thermodiffusion effects on silicon crystal growth and the composition changes resulting from the near-zero gravity environment	Y	100% of the planned objectives were accomplished in the mirror heating facility in the MSDR. This experiment produced the first floating zone silicon crystal grown in space.
Traveling Solvent Growth of Cadmium Telluride, 1ES322	H. Jager, Federal Republic of Germany	Materials Science and Technology	Study the thermodiffusion effects on cadmium telluride crystal growth and the composition changes resulting from the near-zero gravity environment	Y	100% of the planned objectives were accomplished in the mirror heating facility in the MSDR.
Traveling Heater Method of III-V Compounds, Indium-Antimony, 1ES323	K.W. Benz, Federal Republic of Germany	Materials Science and Technology	Study the thermodiffusion effects of indium-antimony crystal growth and the composition changes resulting from the near-zero gravity environment	Y	100% of the planned objectives were accomplished in the mirror heating facility in the MSDR.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Crystallization of Silicon Spheres, 1ES324	Dr. Kolker, Federal Republic of Germany	Materials Science and Technology	Study the thermodiffusion effects on silicon spheres and the composition changes resulting from the near-zero gravity environment	Y	100% of the planned objectives were accomplished in the mirror heating facility in the MSDR.
Unidirectional Solidification of Cast Iron, 1ES325	T. Luyendijk, The Netherlands	Materials Science and Technology	Study cast iron solidification in a near-zero gravity environment to provide knowledge that may apply to industrial processes on Earth	Y	100% of the planned objectives were accomplished using the isothermal heating furnace in the MSDR.
Oscillation Damping of a Liquid in Natural Levitation, 1ES326	H. Rodot, France	Materials Science and Technology	Study the phenomena of natural levitation of a liquid, oscillation damping of the liquid, and hydrodynamics of floating liquid zones	Y	100% of the planned objectives were accomplished in the fluid physics module in the MSDR.
Kinetics of Spreading of Liquids on Solids, 1ES327	J.M. Haynes, United Kingdom	Materials Science and Technology	Study the phenomena of spreading liquids on solids and the kinetics of spreading in a near-zero gravity environment	Y	100% of the planned objectives were accomplished in the fluid physics module in the MSDR.
Free Convection in Low Gravity, 1ES328	L.G. Napolitano, Italy	Materials Science and Technology	Study the phenomena of free convection in a near-zero gravity environment	Y	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Other data were also successfully collected.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Capillary Surfaces in Low Gravity, 1ES329	J.F. Padday, United Kingdom	Materials Science and Technology	Study the phenomena of capillary surfaces in near-zero gravity and the hydrodynamics of floating liquid zones	Y	100% of the planned objectives were accomplished in the fluid physics module in the MSDR.
Coupled Motion of Liquid-Solid Systems in Near-Zero Gravity, 1ES330	J.P.B. Vreeburg, The Netherlands	Materials Science and Technology	Study the phenomena of coupled motion of a liquid-solid system in near-zero gravity and the hydro-dynamics of floating liquid zones	Y	100% of the planned objectives were accomplished in the fluid physics module in the MSDR.
Floating Zone Stability in Zero-Gravity, 1ES331	I. Da Riva, Spain	Materials Science and Technology	Study the phenomena of floating zone stability of a liquid in near-zero gravity	Y	100% of the planned objectives were accomplished in the fluid physics module in the MSDR. Other data were also successfully collected.
Organic Crystal Growth, 1ES332	K.F. Nielsen, Denmark	Materials Science and Technology	Study organic crystal growth in near-zero gravity and the effect of weightlessness on the crystals	Y	Approximately 100% of the planned objectives were accomplished.
Growth of Manganese Carbonate, 1ES333	A. Authier, France	Materials Science and Technology	Study the growth of manganese carbonate in near-zero gravity and the effect of weightlessness on the manganese carbonate	Y	Approximately 100% of the planned objectives were accomplished.
Crystal Growth of Proteins, 1ES334	W. Littke, Federal Republic of Germany	Materials Science and Technology	Study crystal growth of proteins in near-zero gravity and the effects of weightlessness on the crystals	Y	Approximately 100% of the planned objectives were accomplished.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Self-Diffusion and Inter-Diffusion in Liquid Metals, 1ES335	Dr. Kraatz, Federal Republic of Germany	Materials Science and Technology	Study self-diffusion and inter-diffusion in liquid metals exposed to near-zero gravity and the effect of weightlessness on the liquid metals	Y	Approximately 100% of the planned objectives were accomplished.
Crystal Growth of Mercury Iodide by Physical Vapor Transport, 1ES338	C. Belouet, France	Materials Science and Technology	Study crystal growth of mercury iodide by physical vapor transport in near-zero gravity and the effect of weightlessness on the mercury iodide crystals	Y	Approximately 100% of the planned objectives were accomplished.
Interfacial Instability and Capillary Hysteresis, 1ES339	J.M. Haynes, United Kingdom	Materials Science and Technology	Study interfacial instability and capillary hysteresis in a near-zero gravity environment	Y	100% of the planned objectives were accomplished in the fluid physics module in the MSDR.
Adhesion of Metals, Ultra High Vacuum Chamber, 1ES340	G. Ghersini, Italy	Materials Science and Technology	Study adhesion of metals in an ultrahigh vacuum chamber in a near-zero gravity environment	Y	Approximately 100% of the planned objectives were accomplished.
Tribiological Experiments in Zero-Gravity, 1NT011	C.H.T. Pan, F. Whitaker and R.L. Gause, United States	Materials Science and Technology	Study the wetting and spreading phenomena and fluid distribution patterns in a near-zero gravity environment	Y	100% of the planned objectives were accomplished. Other data were also successfully collected.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
An Imaging Spectrometric Observatory, 1NS001	M.R. Torr, United Sates	Atmospheric Physics and Earth Observations	Measure the airglow spectrum in wavelengths ranging from extreme ultraviolet to infrared	P	Approximately 75% to 80% of the planned objectives were accomplished. The Imaging Spectrometric Observatory (ISO) obtained the first broad-band spectrum of dayglow from 300 to 12,800 angstroms. It also obtained a database for a detailed assessment of the Shuttle environment for optical remote sensing in the visible, ultraviolet, and near-infrared ranges. The ISO obtained additional data concurrent with the electron beam firings and neutral releases. All science functional tests were run and the data were recorded. Because of RAU21, HDRR, and TDRSS coverage problems, some data were lost.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Grille Spectrometer. 1ES013	M. Ackerman, Belgium; A. Girard, France	Atmospheric Physics and Earth Observations	Study, on a global scale, the atmosphere between 15 km and 150 km altitude	P	The low percentage of planned objectives accomplished (16%) was from the large beta angle constraint caused by the launch delay from October to November. The first observations of CO_2 in the thermosphere and water and methane in the mesosphere were made. Other gases were also observed. Solar absorption spectra of the atmospheric Earth limb in infrared light at sunset and sunrise were taken with a spectral resolution better than 10.0. Atmospheric absorptions were observed from 12 km to 130 km.
Waves in the Oxygen-Hydrogen Emissive Layer, 1ES014	M. Herse, France	Atmospheric Physics and Earth Observations	Photograph a layer of the high atmosphere to examine cloudlike structures that were observed within that layer	Y	100% of the planned objectives were accomplished. In addition to the planned photography, other measurements were taken.

Table 4-45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Investigation on Atmospheric Hydrogen and Deuterium through the Measurement of Their Lyman-Alpha Emission, 1ES017	J.L. Bertaux, France	Atmospheric Physics and Earth Observations	Study various sources of Lyman-Alpha emission in the atmosphere, in interplanetary space, and possibly in the galactic medium	P	Approximately 80% of the planned objectives were accomplished. Deuterium was discovered in the upper atmosphere between 100 km and 150 km. This discovery would allow for determination of the atmospheric eddy diffusion coefficient. The atomic hydrogen vertical profile between 80 km and 250 km was determined, and observations of interplanetary Lyman-Alpha emission were successful.
Metric Camera Experiment, 1EA033	M. Reynolds, Federal Republic of Germany	Atmospheric Physics and Earth Observations	Test the mapping capabilities of high-resolution photography from space	P	Approximately 80% of the planned objectives were accomplished. Although the metric camera experienced a jammed film advance mechanism, an in-flight maintenance procedure was developed to correct the problem. In addition to the planned observations, several targets of opportunity were photographed.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Microwave Remote Sensing Experiment, 1EA034	G. Dieterle, Federal Republic of Germany	Atmospheric Physics and Observations	Develop an all-weather microwave remote-sensing system	P	Approximately 20% of the planned objectives were accomplished because of primary experiment equipment malfunctions. Measurements were taken over the planned target areas using the backup radiometer mode. In addition to the planned objectives, other data were obtained.
Atmospheric Emission Photometric Imaging (AEPI), 1NS003	S.B. Mende, United States	Space Plasma Physics	Observe faint optical emissions associated with natural and artificially induced phenomena (such as auroras) in the upper atmosphere	P	The AEPI operated with the camera in the stowed position because of a hardware failure, but as a result of orbiter maneuvers, the payload specialists were able to successfully complete approximately 65% to 70% of the planned objectives. Principal investigators gathered significant diagnostic data during joint operations with SEPAC. Information was also gathered about the double-layer airglow phenomena.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Space Experiments With Particle Accelerators (SEPAC), 1NS002	T. Obayashi, Japan	Space Plasma Physics	Perform active and interactive perturbation experiments in Earth's ionosphere and magnetosphere	P	Approximately 80% of the planned objectives were accomplished. Vehicle charge neutralization was accomplished by the Magnetoplasma Dynamic Arcjet (MPD). A suspected-but-never-proven beam plasma discharge phenomenon was observed. Scientific experiments were successful except those requiring high-power electron gun firings. At the start of the SEPAC electron beam high-power firing test, the electron beam accelerator shut down and did not come back on-line for the remainder of the flight. Testing determined that vehicle neutralization was only partially achievable using the neutral gas plume. The planned coordination with the Phenomena Induced by Charged Particle Beams experiment (see below) was successful.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Low Energy Electron Flux and Its Reaction to Active Experimentation on Spacelab, 1ES019A	K. Wilhelm, Federal Republic of Germany	Space Plasma Physics	Use artificially accelerated electrons as tracer particles for electric fields parallel to Earth's magnetic field	P	Approximately 90% of the planned objectives were accomplished. Principal investigators detected detailed high-resolution auroras when operating with SEPAC. However, failure of the SEPAC high-power electron beam limited the results.
Direct Current Magnetic Field Vector Measurement, 1ES019B	R. Schmidt, Austria	Space Plasma Physics	Determine the magnetic field surrounding the orbiter during the Spacelab 1 mission	P	Approximately 90% of the planned objectives were accomplished. Only the failure of the SEPAC high-power electron beam limited the results.
Phenomena Induced by Charged Particle Beams, 1ES020	C. Beghin, France	Space Plasma Physics	Study the effects of charged particle beam injections into Earth's upper atmosphere	P	All primary independent objectives were met. The planned coordination experiment with SEPAC was completed successfully. Loss of some data was experienced because of a gas bottle failure and the AEPI camera lock problem. This resulted in 60% of all planned objectives being accomplished.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Isotopic Stack-Measurement of Heavy Cosmic Ray Isotopes, 1ES024	R. Beaujean, Federal Republic of Germany	Space Plasma Physics	Measure heavy cosmic ray nuclei with a nuclear charge of 3 or more	Y	100% of the planned objectives were accomplished.
Far Ultraviolet Astronomy Using the FAUST Telescope, 1NS005	S. Bowyer, France	Astronomy and Solar Physics	Observe faint ultraviolet emissions from various astronomical sources with higher sensitivity than previously possible	P	Approximately 96% of the planned objectives were accomplished. Other targets were photographed in addition to the planned objective.
Very Wide Field Camera, 1ES022	G. Courtes, France	Astronomy and Solar Physics	Make a general ultraviolet survey of the celestial sphere in a study of large-scale phenomena	Y	100% of the planned objectives were accomplished. All primary targets were photographed, plus additional targets and spectra.
Spectroscopy in X-Ray Astronomy, 1ES023	R. Andresen, The Netherlands	Astronomy and Solar Physics	Study detailed features of cosmic x-ray sources and their variations in time	Y	100% of the planned objectives were accomplished. Measurements of the iron emission from the supernova remnant Cassiopeia A and the iron emission from Cygnus X-3 were taken. Additional measurements were obtained from other targets.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Active Cavity Radiometer, 1NA008	R.C. Wilson, United States	Astronomy and Solar Physics	Measure the total solar irradiance and its variation through time with state-of-the-art accuracy and precision	P	Approximately 90% of the planned objectives were accomplished.
Measurement of the Solar Constant, 1ES021	D. Crommelynck, Belgium	Astronomy and Solar Physics	Measure the absolute value of the solar constant with improved accuracy and to detect and measure long-term variations	P	Solar constant measurements were made with undetermined results. 90% of the planned objectives were completed.
Solar Spectrum from 170-3200 Nanometers, 1ES016	G. Thuillier, France	Astronomy and Solar Physics	Measure the energy output in the ultraviolet-to-infrared range of the solar spectrum	Y	100% of the planned objectives were accomplished. All of the scheduled observations were completed, and additional data were obtained.
Effects of Rectilinear Accelerations, Optokinetic, and Caloric Stimulations in Space, 1ES201	R. von Baumgarten, Federal Republic of Germany	Life Sciences	Investigate the vestibular functions of the inner ear, particularly the otolith organs that help maintain balance	P	Approximately 75% of the planned objectives were accomplished. Results were highly successful in the linear threshold, oscillopcia, and caloric operations.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Vestibular Experiments, 1NS102	L.R. Young, United States	Life Sciences	Study the causes of space motion sickness and to study sensory-motor adaptation to weightlessness	P	Approximately 90% of the planned objectives were accomplished. Several experiments were performed, including the rotating dome, "hop and drop," and provocative testing. Data quality was excellent. Additional exploratory investigations were also done.
Vestibulo-Spinal Reflex Mechanisms, 1NS104	M.F. Reschke, United States	Life Sciences	Observe changes in spinal reflexes and posture during sustained weightlessness	P	Approximately 85% of the planned objectives were accomplished.
The Influence of Space Flight on Erythrokinetics in Man, 1NS103	C.S. Leach, United States	Life Sciences	Measure changes in the circulating red blood cell mass of people exposed to weightlessness	Y	100% of the planned objectives were accomplished.
Measurement of Central Venous Pressure and Determination of Hormones in Blood Serum During Weightlessness, 1ES026 and 1ES032	K. Kirsch, Federal Republic of Germany	Life Sciences	Collect data on changes in the distribution of body fluids and in the balance of water and minerals in the blood	Y	100% of the planned objectives were accomplished. Excellent television coverage of blood work and venous pressure activity was downlinked.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Effects of Prolonged Weightlessness on the Humoral Immune Response of Humans, 1NS105	E.W. Voss, Jr., United States	Life Sciences	Determine the effect of weightlessness on the body’s immune response or ability to resist disease	Y	100% of the planned objectives were accomplished.
Effect of Weightlessness on Lymphocyte Proliferation, 1ES031	A. Cogoli, Switzerland	Life Sciences	Study the effect of weightlessness on lymphocyte activation	Y	100% of the planned objectives were accomplished.
Three-Dimensional Ballistro-cardiography in Weightlessness, 1ES028	A. Scano, Italy	Life Sciences	Record a three-dimensional ballistrocardiogram under a unique condition and to compare the results with tracings recorded on the same subject on the ground	Y	100% of the planed objectives were accomplished. Several additional runs were completed.
Personal Miniature Electro-physiological Tape Recorder, 1ES030	H. Green, United Kingdom	Life Sciences	Collect physiological data on a normal man in an abnormal environment as a basis for future studies	Y	100% of the planned objectives were accomplished.
Mass Discrimination During Weightlessness, 1ES025	H. Ross, United Kingdom	Life Sciences	Compare the perception of mass in space with the perception of weight on Earth	P	Approximately 90% of the planned objectives were accomplished. The crew’s performance of mass discrimi-nation was significantly poorer in near-zero gravity than in a one-gravity environment.

Table 4–45 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Nutation of Helianthus Annuus in a Microgravity Environment, 1NS101	A.H. Brown, United States	Life Sciences	Observe the growth movements of plants in a near-zero gravity environment	P	Approximately 60% of the planned objectives were accomplished. Experiment camera synchronization problems might have caused some loss of data.
Preliminary Characterization of Persisting Circadian Rhythms During Spaceflight: Neurospora as a Model System, 1NS007	F.M. Sulzman, United States	Life Sciences	Compare the growth of plants cultured in Spacelab and on the ground to test whether circadian rhythms persist in space	Y	100% of the planned objectives were accomplished. The implanted fungus demonstrated circadian growth within a 24-hour period.
Microorganisms and Biomolecules in Hard Space Environment, 1ES029	G. Horneck, Federal Republic of Germany	Life Sciences	Measure the influence of the space environment on various biological specimens	Y	100% of the planned objectives were accomplished.
Radiation Environment Mapping, 1NS006	E.V. Benton, United States	Life Sciences	Measure the cosmic radiation inside Spacelab	Y	100% of the planned objectives were accomplished.
Advanced Biostack Experiment, 1ES027	H. Bucker, Federal Republic of Germany	Life Sciences	Determine the radiobiological importance of cosmic radiation particles of high charge and high energy	Y	100% of the planned objectives were accomplished.

Table 4–46. Spacelab 3 Experiments

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Solution Growth of Crystals in Zero-Gravity, Fluid Experiment System (FES)	R. Lal, United States	Materials Science	Develop a technique for solution crystal growth in a near-zero gravity environment, to characterize the growth environment under orbital conditions and its influence on crystal growth behavior, and to evaluate the properties of the resultant crystal	Yes (Y)	During the first flight of the new fluid experiment system, two triglycine sulfate crystals were successfully grown from a liquid. For the first time, scientists could see in detail the crystal growth process in a microgravity environment and determine the differences between crystal growth on the ground and growth in microgravity where convection effects are negligible. Visual observations by the crew provided real-time descriptions of the crystal and aided investigators on the ground as they controlled the progress of the investigation.
Mercuric Iodide Growth, Vapor Crystal Growth System (VCGS)	W.F. Schnepple, United States	Materials Science	Grow higher quality mercuric iodide crystals in a near-zero gravity environment and to gain an improved understanding of crystal growth by a vapor process	Y	A mercury iodide crystal measuring 14 mm x 8 mm x 7 mm was successfully grown from a seed crystal 20 times smaller in this new facility by a vapor transport process. The crystal grew at a carefully controlled rate, varying from 1 mm to 3 mm per day.

Table 4–46 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Mercury Iodide Crystal Growth (MICG)	R. Cadoret, France	Materials Science	Grow near-perfect single crystals of mercury iodide in a near-zero gravity environment at different pressures to analyze the effects of the environment on vapor transport	Y	Six cartridges of mercury iodide material without seed crystals were processed for up to 70 hours at a time, each under different growth conditions.
Dynamics of Rotating and Oscillating Free Drops, Drop Dynamics Module (DDM)	T. Wang, United States	Fluid Mechanics	Perform fundamental experiments to verify that the new facility can acoustically manipulate drops, to test theoretical predictions of drop behavior, and to observe any new phenomena encountered	Y	After initial startup difficulties, this facility underwent significant in-flight maintenance and operated successfully for research in the behavior of free floating drops. For the first time, a principal investigator operated and repaired his own experiment in space as a Spacelab crew member. Interaction between the ground team and flight crew resulted in investigation recovery and the accomplishment of virtually all the intended research.

Table 4–46 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Geophysical Fluid Flow Cell (GFFC)	J. Hart, United States	Fluid Mechanics	Study fluid motions in a near-zero gravity environment to understand fluid flows in oceans, atmospheres, and stars and test an elaborate new facility for laboratory experiments on geophysical flows	Y	The GFFC facility performed nominally and obtained excellent data. All planned scenarios were performed during an 84-hour period, and the mission added 13 unscheduled scenarios in 18 hours of extra operations. Approximately 46,000 shadow-graph images, which permitted the fluid density gradients to be observed, were recorded on film for postflight analysis.

Table 4–46 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Ames Research Center Life Sciences Payload (ARCLSP)	P. Callahan, J. Tremor, United States	Life Sciences	Perform engineering tests to ensure that the Research Animal Holding Facility was a safe and adequate facility for housing and studying animals in the space environment, observe the animals' reactions to the space environment, and evaluate the operations and procedures for in-flight animal care	Y	The new Research Animal Holding Facility provided a suitable animal habitat. However, there were some difficulties with food and waste containment. Food, water, and activity monitors provided good engineering data about the facility and the status of the animals; they adjusted well to spaceflight and demonstrated their suitability for research in orbit. One of the two primates developed symptoms of space adaptation syndrome but recovered in a manner analogous to human experience. This suggests that nonhuman primates may be good models for vestibular research pertinent to human adaptation of microgravity. The Biotelemetry System provided data on physiological functions of four rodents.

Table 4–46 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Autogenic Feedback Training (AFT)	P. Cowlings, United States	Life Sciences	Test a treatment for space adaptation syndrome and to test a technique for training people to control bodily processes voluntarily	Y	In general, the hardware performed nominally and did not interfere with other crew activities.
Urine Monitoring System (UMS)	H. Schneider, United States	Life Sciences	Verify the operation of the UMS in collecting and sampling urine, perform in-flight measurement system calibration, develop and utilize a procedure for monitoring crew water intake using existing orbiter facilities, and verify the system for preparing urine samples for postflight analysis	Y	All planned calibrations and dead volume measurements were performed, but urine samples were collected for only one rather that two crew members as planned.
Very Wide Field Camera (VWFC)	G. Courtes, France	Atmospheric Science and Astronomy	Make an ultraviolet survey of the celestial sphere in a study of large-scale phenomena, such as clouds, within our galaxy	Partial (P)	The VWFC operated nominally on its first deployment but could not be subsequently deployed when the bent latch handle on the scientific airlock precluded further airlock operations. Ground teams assessed the airlock malfunction but determined that in-flight maintenance was inappropriate. During the initial extension into space, the camera acquired its first target and made a 1-minute exposure. However, the five subsequent operations were suspended.
Auroral Imaging Experiment	T. Hallinan, United States	Atmospheric Science and Astronomy	Observe and record the visual characteristics of pulsating and flickering auroras	P	Of the 21 scheduled opportunities for auroral observations, 18 were accomplished, with auroras clearly visible on each.

Table 4–46 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Atmospheric Trace Molecules Spectroscopy (ATMOS)	C.B. Farmer, United States	Atmospheric Science and Astronomy	Obtain fundamental information related to the chemistry and physics of Earth's upper atmosphere using infrared absorption spectroscopy, determine, on a global scale, the compositional structure of the upper atmosphere and its spatial variability, and provide the high-resolution, calibrated spectral information essential for the detailed design of advanced instrumentation for future global monitoring of species critical to atmospheric stability	Y	Although the ATMOS instrument was deactivated earlier than planned, the investigation was one of the most successful of the mission. In 19 3-minute operations, ATMOS obtained 150 independent atmospheric spectra, each of which contained at least 100,000 individual spectral measurements. During five solar calibrations, detailed infrared spectra of the Sun were obtained. Initial examination of the data indicated unexpected evidence about molecular constituents there.
Studies of the Ionization States of Solar and Galactic Cosmic Ray Heavy Nuclei (IONS)	S. Biswas, India	Atmospheric Science and Astronomy	Use a newly designed detector system to determine the composition and intensity of energetic ions emitted from the Sun and other galactic sources toward Earth's atmosphere	Y	IONS provided data on the arrival time and directions in space of cosmic ray particles and hence the magnetic rigidity. During the mission, the instrument initially did not respond to commands to rotate the detector stack. After in-flight maintenance was performed, the instrument operated nominally. The investigation accomplished two-thirds of its operational timeline.

Table 4–47. Spacelab 2 Experiments

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Vitamin D Metabolites and Bone Demineralization, 2SL-01	H.K. Schnoes, United States	Life Sciences	Measure quantitatively the blood levels of biologically active vitamin D metabolites of the Spacelab 2 flight crew members	Yes (Y)	100% of the planned objectives were accomplished.
Interaction of Oxygen and Gravity Influenced Lignification, 2SL-02	J.R. Cowles, United States	Life Sciences	Determine the effect of weightlessness upon lignification and to establish the overall effect of oxygen on lignin formation independent of any gravity effects	Y	100% of the planned objectives were accomplished. The real-time downlinked video from this experiment exceeded expectations in both quantity and quality.
Ejectable Plasma Diagnostics Package (PDP), 2SL-03	L.A. Frank, United States	Plasma Physics	Study natural plasma processes, orbiter-induced plasma processes, and beam plasma physics	Partial (P)	Approximately 82% of the objectives were accomplished. Some of the attached operations on the Remote Manipulator System (RMS) arm and one orbiter fly-around were lost because of low propellant levels. However, the PDP performed flawlessly on the pallet, with the RMS, and as a free-flyer.
Plasma Depletion Experiments for Ionospheric and Radio Astronomical Studies, 2SL-04	M. Mendillo and A.V. DaRosa, United States	Plasma Physics	Study the ionospheric depletions and related effects caused by the exhaust gases from the orbiter Orbital Maneuvering System (OMS) burns	P	50% of the planned objectives were accomplished. Only four of eight planned OMS burns were performed because of low OMS propellant. The Millstone Hill and Arecibo burns created ionospheric holes deeper and wider than expected.

Table 4–47 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Small Helium-Cooled Infrared Telescope, 2SL-05	G.G. Fazio, United States	Infrared Astronomy	Study the diffuse emission and extended sources in the infrared sky, the measurement of the natural and spacecraft-induced infrared background, and the determination of suitable procedures and techniques for the in-space use of superfluid helium and cryogenic telescopes	P	The infrared telescope operated well throughout the mission but did not achieve its primary objective of an all-sky survey. During the first viewing period, many of the detectors were quickly saturated by a strong source of mysterious origin. A survey of the instrument with the RMS camera before payload deactivation revealed apparent debris within the sun shade. A section of the galaxy was mapped in shorter wavelengths. These few minutes of data represent a new and valuable complement to the infrared astronomical satellite data. Evaluations were also made of the dewar system, and several attempts were made to alter the state of the superfluid helium to observe the fluid dynamic behavior.

Table 4–47 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Elemental Composition and Energy Spectra of Cosmic Ray Nuclei, 2SL-06	P. Meyer and D. Muller, United States	High-Energy Physics	Determine the abundance distributions of elements and isotopes in the cosmic radiation, study the composition of cosmic rays at high energies, investigate the role of a galactic halo in particle confinement, and determine whether the relative abundancies of different source nuclei change with energy	Y	100% of the planned objectives were accomplished.
Hard X-Ray Imaging of Clusters of Galaxies and Other Extended X-Ray Sources, 2SL-07	A.P. Willmore, United Kingdom	High-Energy Physics	Use x-ray measurements to observe a component of galaxies and study their temperatures and mass distribution, understand the properties of intergalactic gas emitted from clusters of galaxies, use the x-ray observations to determine the spectrum and distribution of gigaelectron volt electrons in the clusters of galaxies, and use x-ray observations to demonstrate the differences between clusters of galaxies	P	Approximately 90% of the planned objectives were accomplished. The dual x-ray telescope operated well throughout the mission with very good image quality, detector sensitivity, and stability. Images of point sources and extended sources were successfully reconstructed from downlinked data.

Table 4–47 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Solar Magnetic and Velocity Field Measurement System, 2SL-08	A.M. Title, United States	Solar Physics	Measure magnetic and velocity fields in the solar atmosphere, follow the evolution of solar magnetic structure over several days, study magnetic field changes associated with transient events, and provide a test of the pointing accuracy and stability of the IPS	Y	The Solar Optical Universal Polarimeter started its observations late in the mission after an unexplained shutdown on the first day and an equally unexplained startup on the next-to-the-last day of the mission. (See the "Mission Anomalies" section.) Thereafter, the instrument performed almost perfectly to observe the strength, structure, and evolution of magnetic fields in the solar atmosphere.
Solar Coronal Helium Abundance Spacelab Experiment, 2SL-09	A.H. Gabriel and J.L. Culhane, United Kingdom	Solar Physics	Determine accurately the abundance of helium in the solar atmosphere	P	Approximately 66% of the objectives were accomplished. Early mission observing time was lost because of difficulties with the IPS. However, spectral scans of the limb of the solar disc were achieved. In addition, the instrument was used in a mapping mode to study and make images of the structure of the Sun's corona.

Table 4–47 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Solar Ultraviolet High Resolution Telescope and Spectrograph, 2SL-10	G.E. Brueckner, United States	Solar Physics	Make spectral scans and images of the solar disc and, particularly, record rapidly changing solar features	P	Approximately 60% of the objectives were accomplished. The resolution of the telescope was very good, but IPS pointing difficulties compromised the early data. Downlink television from the instrument revealed the birth of a spicule, which was never witnessed before.
Solar Ultraviolet Spectral Irradiance Monitor, 2SL-11	G.E. Brueckner, United States	Atmospheric Physics	Improve the accuracy of knowledge of the absolute solar fluxes, provide a highly accurate traceability of solar fluxes, and measure the variability of solar fluxes	P	Approximately 50% of the planned objectives were accomplished. The experiment made spectral scans of the Sun with excellent accuracy, verified by calibration and alignment checks.
Vehicle Charging and Potential, 2SL-14	P.M. Banks, United States	Plasma Physics	Investigate electron beam interactions in space plasma, vehicle charging processes, and electromagnetic wave generation processes	P	Approximately 72% of the objectives were accomplished. Television images of beam and aurora activities were not permitted because of bright moonlight. Joint operations and observations were accomplished, primarily with the PDP and with the nearby Dynamics Explorer satellites. The electron generator was fired more than 200 times. Instrument performance was nearly perfect.

Table 4–47 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Properties of Superfluid Helium in Zero-Gravity, 2SL-13	P.V. Mason, United States	Technology	Determine the fluid and thermal properties that are required for the design of planned space experiments using superfluid helium as a cryogen, advance scientific understanding of the interactions between superfluid and normal liquid helium, and demonstrate the use of superfluid helium as a cryogen in zero-gravity	P	Approximately 88% of the objectives were accomplished. The dewar or cryosat performed as expected during the mission. The existence of quantized surface waves in thin films of helium was clearly established, and several hundred recordings were made across a range of temperatures. Bulk thermal dynamics measurements of temperature variations within the dewar were quite successful. However, bulk fluid dynamics measurements were prevented by sensors, which remained frozen throughout the mission.

Table 4–47 continued

Experiment/ Number	Principal Investigator	Class	Purpose/Objective	Success	Result
Protein Crystal Growth	C.E. Bugg, United States	Technology	Develop hardware and procedures for growing proteins and other organic crystals by two methods in the orbiter during the low-gravity portion of the mission	Y	Generally, hardware for both methods worked as planned. Postflight analysis showed minor modification in the flight hardware was needed, and a means of holding the hardware during activation, crystal growth, deactivation, and photography was desirable. The dialysis method produced three large tetragonal lysozyme crystals with average dimensions of 1.3 mm x 0.65 mm x 0.65 mm. The solution growth methods produced small crystals of lysozyme, alpha-2 interferon, and bacterial purine nucleoside phosphorylase.

Table 4–48. Spacelab D-1 Experiments

Experiment/Number	Investigator/Sponsor	Class
Floating Zone Hydrodynamics, FPM 04	J. Da Riva, U. Madrid, Spain	Fluid Physics
Capillary Experiments in Low Gravity Fields, FPM 06	J.F. Padday, Kodak, Ltd., Harrow, United Kingdom	Fluid Physics
Forced Liquid Motions, FPM 08	J.P.B. Vreeburg, NAL, Amsterdam, The Netherlands	Fluid Physics
Oberflachenspannung (Surface Tension Studies), HOL 03	D. Neuhaus, DFVLR, Koln, Germany	Fluid Physics
Maragonikonvektion Im Offenen Boot (Marangoni Convection), MKB 00	D. Schwabe, U. Gieben, Germany	Fluid Physics
Marangoni Flows, FPM 07	L. Napolitano, U. Neapel, Italy	Fluid Physics
Marangoni Convection in Gas-Liquid Mass Transfer, FPM 01	A.A.H. Drinkenburg, U. Groningen, The Netherlands	Fluid Physics
Convection in Nonisothermal Binary Mixture Presenting a Surface Tension Minimum as a Function of Temperature, FPM 05	J.C. Legros, U. Brussels, Belgium	Fluid Physics
Blasentransport (Bubble Transport), HOL 01	A. Bewersdorff, DFVLR, Koln, Germany	Fluid Physics
Selbst- und Interdiffusion (Self- and Inter-Diffusion), HTT 00	K.H. Kraatz, H. Wever, G. Frohberg, TU Berlin, Germany	Fluid Physics
Thermal Diffusion, GHF 01	J. Dupuy, U. Lyon, France	Fluid Physics
Interdiffusion, IDS 00	W. Merkens, TH Aachen, Germany	Fluid Physics
Homogenitat von Glasern (Homogeneity of Glasses), IHF 05	Chr. Frischat, TU Clausthal, Germany	Fluid Physics
Diffusion of Liquid Zinc and Lead, GPRF 2	R.B. Pond, Marvalaud Inc., United States	Fluid Physics
Thermomigration of Cobalt in Tin, GHF 07	J.P. Praizey, CEN, Grenoble, France	Fluid Physics
Warmekapazitat am Kritischen Punkt (Heat Capacity Near Critical Point), HPT 00	J. Straub, TU Munchen, Germany	Fluid Physics
Phasenbildung am Kritischen Punkt (Phase Separation Near Critical Point), HOL 02	H. Klein, DFVLR, Koln, Germany	Fluid Physics
GETS, HOL 04	A. Ecker, TH Aachen, Germany	Solidification

Table 4–48 continued

Experiment/Number	Investigator/Sponsor	Class
Al-Cu, Phasengrenzflachendiffusion (Aluminum-Copper Phase Boundary Diffusion), GFQ 01	H.M. Tensi, TU Munchen, Germany	Solidification
Erstarrungskonvektion (Solidification Dynamics), GFQ 02	S. Rex, TH Aachen, Germany	Solidification
Dendritic Solidification of Aluminum-Copper Alloys, GHF 04	J.J. Favier, D. Camel, CEN, Grenoble, France	Solidification
Cellular Morphology in Lead Thallium Alloys, GHF 02	B. Billia/J. Favier, U. Marseilles, France	Solidification
InSb-NiSb-Eutektikum (Indium Antimonide-Nickel Antimonide Eutectics), ELI 04	G. Muller, U. Erlangen-Nurnberg, Germany	Solidification
Containerless Melting of Glass, SAAL	D.E. Day, U. Missouri-Rolla, United States	Solidification
Suspensionserstarrung (Solidification of Suspensions), IHF 02	J. Potschke, Krupp-Forschungsinst Essen, Germany	Solidification
Teilchen vor Schmelz und Erstarrungsfront (Particle Behavior at Solidification Fronts), IHF 06	D. Langbein, Battelle-Inst., Frankfurt, Germany	Solidification
Stutzhauttechnologie (Skin Technology), IHF 03	H. Sprenger, MAN, Munchen, Germany	Solidification
Liquid Skin Casting of Cast Iron, IHF 07	H. Sprenger, MAN, Munchen, Germany	Solidification
Erstarrung eutsktischer Legierungen (Solidification of Eutectic Alloys), IHF 09	Y. Malmejac, CEN, Grenoble, France	Solidification
Erstarrung von Verbundmaterialien (Solidification of Composite Materials), IHF 08	A. Deruyttere, U. Leuven, Germany	Solidification
Shmelzzonenzuchtung Si (Silicon-Crystal Growth by Floating Zone Technique), MHF 01	R. Nitsche, A. Croll, U. Freiburg/Br., Germany	Solidification
Si-Kugel (Melting of Silicon Sphere), MHF 04	H. Kolker, Wacker-Chemie, Munchen, Germany	Solidification
Doped Indium Antimonide and Gallium Indium Antimonide, GHF 03	C. Potard, CEN, Grenoble, France	Solidification
Traveling Heater Method (GaSb), MHF 02	K.W. Benz, U. Stuttgart, Germany	Solidification

Table 4–48 continued

Experiment/Number	Investigator/Sponsor	Class
Traveling Heater Method (CdTe), MHF 03	R. Schonholz, R. Freiburg/Br., Germany	Solidification
Traveling Heater Method (InP), ELI 01	K.W. Benz, U. Stuttgart, Germany	Solidification
Traveling Heater Method (PbSnTe), ELI 02	M. Harr, Battelle-Inst, Frankfurt, Germany	Solidification
Gaszonenzuchtung CdTe (Vapor Growth of Cadmium), ELI 03	M. Bruder, U. Freiburg/Br., Germany	Solidification
Ge/Gel4 Chemical Growth, GHF 05	J.C. Launay, U. Bordeaux, France	Solidification
Ge-I2 Vapor Phase, GHF 06	J.C. Launay, U. Bordeaux, France	Solidification
Vapor Growth of Alloy-Type Crystal, GPRF 4	H. Wiedemeier, Rensalear Polytechnic Institute, Troy, New York, United States	Solidification
Semiconductor Materials, GPRF 5	R.K. Crouch, Langley R.C., United States	Solidification
Proteinkristalle (Protein Crystals), CRY 00	W. Littke, R. Freiburg/Br., Germany	Solidification
Separation Nichmischbarer Legierungen (Separation of Immiscible Alloys), IHF 01	H. Ahlborn, U. Hamburg, Germany	Solidification
Separation of Immiscible Liquids, FPM 03	D. Langbein, Battelle-Inst., Frankfurt, Germany	Solidification
Separation of Fluid Phases, FPM 02	R. Naehle, DFVLR, Koln, Germany	Solidification
Liquid Phase Miscibility Gap Materials, GPRF 3	H.S. Gelles, Columbus, Ohio, United States	Solidification
Ostwaldreifung (Ostwald Ripening), IHF 04	H. Fischmeister, MPI, Stuttgart, Germany	Solidification
Human Lymphocyte Activation, BR 32CH	A. Cogoli, ETH Zurich, Switzerland	Biology
Cell Proliferation, BR 21 F	H. Planel, U. Toulouse, France	Biology
Mammalian Cell Polarization, BR 48 F	M. Bouteille, U. Paris, France	Biology
Circadian Rhythm, BR 27 D	D. Mergenhagen, U. Hamburg, Germany	Biology
Antibacterial Activity, BR 58 F	R. Tixador, U. Toulouse	Biology
Growth and Differentiation of Bacillus Subtilis, BR 28 D	H.D. Mennigmann, U. Frankfurt, Germany	Biology
Effect of Microgravity in Interaction Between Cells, BR 07 I	O. Ciferri, U. Pavia, Italy	Biology
Cell Cycle and Protoplasmic Streaming, BR 16 D	V. Sovick, DFVLR, Koln, Germany	Biology

Table 4–48 continued

Experiment/Number	Investigator/Sponsor	Class
Dosimetric Mapping Inside Biorack, BR 19 D	H. Bucker, DFLVR, Koln, Germany	Biology
Froschstatolith (Frog Statoliths), STA 00	J. Neubert, DFVLR, Koln, Germany	Biology
Dorsoventral Axis in Developing Embryos, BR 52NL	G. Ubbels, U. Utrecht, The Netherlands	Biology
Distribution of Cytoplasmic Determinants in the Drosophilia Melanogaster Egg, BR 15 E	R. Marco, U. Madrid, Spain	Biology
Embryogenesis and Organogenesis of Caracausius Morosus, BR 18 D	H. Bucker, DFVLR, Koln, Germany	Biology
Graviperzeption (Gravi-Perception), BOT 01	D. Volkmann, U. Bonn, Germany	Biology
Geotropismus (Geotropism), BOT 02	J. Gross, U. Tubingen, Germany	Biology
Differenzierung (Differentiation of Plant Cells), BOT 03	R.R. Theimer, U. Munchen, Germany	Biology
Statocyte Polarity and Geotropic Response, BR 39 F	G. Perbal, U. Paris, France	Biology
Vestibular Research,VS-ES 201	R.V. Baumgarten, U. Mainz, Germany	Medicine
Vestibular Research,VS-NS 102	L. Young, MIT, Cambridge, Massachusetts, United States	Medicine
Zentraler Venendruck (Central Venous Pressure), ZVD 00	K. Kirsch, FU Berlin, Germany	Medicine
Tonometer, TOM 00	J. Draeger, U. Hamburg, Germany	Medicine
Body Impedance Measurement, BIM 300	F. Baisch, DFVLR, Koln, Germany	Medicine
Mass Discrimination, ROS 230	H.E. Ross,	
U. Stirling, United Kingdom	Medicine	
Spatial Description in Space, LAN 200 SDS 00	A.D. Friederici, MPI, Nijmegen, The Netherlands	Medicine
Gesture and Speech in Microgravity, LAN 200GPS 00	A.D. Friederici, MPI, Nijmegen, The Netherlands	Medicine
Reaktionszeitmessung (Determination of Reaction Time), JUF 250	M. Hoschek/J. Hund, Muhltal, Germany	Medicine
Uhrensynchronisation (Clock Synchronization), NX-USY 00	S. Starker, DFVLR, Oberpfaffenhofen, Germany	Navigation
Einwegenthfenungsmessung, NX-EWE 00	D. Rother, SEL, Stuttgart, Germany	Navigation

Table 4–49. OSS-1 Investigations

Investigation	Principal Investigator	Institution
Contamination Monitor Package measured the buildup of molecular and gas contaminants in the orbiter environment to determine how molecular contamination affects instrument performance.	J. Triolo	Goddard Space Flight Center/U.S. Air Force
Microabrasion Foil Experiment measured the numbers, chemistry, and density of micrometeorites encountered by spacecraft in near-Earth orbit.	J.A.M. McDonnell	University of Kent, England
Vehicle Charging and Potential Experiment measured the electrical characteristics of the orbiter, including its interactions with the natural plasma environment of the ionosphere and the disturbances that result from the active emission of electrons.	P. Banks	Utah State University
Shuttle-Spacelab Induced Atmosphere provided data on the extent that dust particles and volatile materials evaporating from the orbiter produced a local "cloud" or "plume" in the "sky" through which astronomical observations could be made.	J. Weinberg	University of Florida
Solar Flare X-Ray Polarimeter measured x-rays emitted during solar flare activities on the Sun.	R. Novick	Columbia University
Solar Ultraviolet Spectral Irradiance Monitor was designed to establish a new and more accurate base of solar ultraviolet irradiance measurements over a wide wavelength region.	G. Brueckner	Naval Research Laboratory
Plant Growth Unit demonstrated the effect of near weightlessness on the quantity and rate of lignin formation in different plant species during early stages of development and tested the hypothesis that, under microgravity, lignin might be reduced, causing the plants to lose strength and droop rather than stand erect.	J.R. Cowles	University of Houston

Table 4–49 continued

Investigation	Principal Investigator	Institution
Thermal Canister Experiment determined the ability of a device using controllable heat pipes to maintain simulated instruments at several temperature levels in thermal loads.	S. Ollendorf	Goddard Space Flight Center
Plasma Diagnostics Package studied the interaction of the orbiter with its surrounding environment, tested the capabilities of the Shuttle's Remote Manipulator System, and carried out experiments in conjunction with the Fast Pulse Electron Generator of the Vehicle Charging and Potential Experiment, also on the OSS-1 payload pallet. The package was deployed for more than 20 hours and was maneuvered at the end of the 15.2-meter RMS. (See also Table 4–40.)	S. Shawhan	University of Iowa

Table 4–50. Hubble Space Telescope Development

Date	Event
1940	Astronomer R.S. Richardson speculates on the possibility of a 300-inch telescope placed on the Moon's surface.
1960/1961	The requests for proposal (RFP) for the Orbiting Astronomical Observatory spacecraft and the astronomical instruments to be flown aboard them are issued.
1962	The National Academy of Sciences recommends the construction of a large space telescope.
1965	The National Academy of Sciences establishes a committee to define the scientific objectives for a proposed large space telescope.
1968	The first astronomical observatory, the Orbiting Astronomical Observatory-1, is launched.
1972	The National Academy of Sciences again recommends a large orbiting optical telescope as a realistic and desirable goal.
1973	NASA establishes a small scientific and engineering steering committee headed by Dr. C. Robert O'Dell of the University of Chicago to determine which scientific objectives would be feasible for a proposed space telescope.
1975	The European Space Agency becomes involved in the project.
1977	NASA selects a group of 60 scientists from 38 institutions to participate in the design and development of the proposed space telescope.
June 17, 1977	NASA issues the Project Approval Document for the space telescope. The primary project objective is to "develop and operate a large, high-quality optical telescope system in space which is unique in its usefulness to the international science community. The overall scientific objectives…are to gain a significant increase in our understanding of the university—past, present, and future—through observations of celestial objects and events...."
Oct. 19, 1977	NASA awards the contract for the primary mirror to Perkin-Elmer of Danbury, Connecticut.
1978	Congress appropriates funds for the development of the space telescope.
April 25, 1978	Marshall Space Flight Center is designated as the lead center for the design, development, and construction of the telescope. Goddard Space Flight Center is chosen to lead the development of the scientific instruments and ground control center.
Dec. 1978	Rough grinding operation begins at Perkin-Elmer in Wilton, Connecticut.
1979	
Jan. 20, 1979	Money requests for space science program increase 20 percent ($100 million), which includes money for the space telescope.
Feb. 1979	Debate over which institute NASA should choose to develop the space telescope takes place. (John Hopkins University is chosen.)

Table 4–50 continued

Date	Event
May 29, 1979	The decision is made to have Fairchild Space & Electronics Company modify the communications and data handling module it developed for NASA's Multimission Modular Spacecraft for use on the space telescope.
June 1979	Marshall Space Flight Center decides that the alternative sensor was receiving little management attention at the Jet Propulsion Laboratory and the space telescope was unlikely to be ready for a 1983 launch.
July 1979	Marshall Space Flight Center compiles its Program Operating Plan for fiscal year 1980; Lockheed and Perkin-Elmer overshot the cost for the space telescope by millions of dollars of the original budgeted adjusted program's reserves.
Nov. 18, 1979	Five states compete for the space telescope: Maryland, New Jersey, Illinois, Colorado, and California. Competing groups include University Research Association, Associated Universities, Inc. (AUI), and Association of Universities for Research and Astronomy (AURA). AUI wants the project at Princeton; AURA wants it at Johns Hopkins University.
Dec. 14, 1979	Goddard Space Flight Center releases the Space Telescope Science Institute RFP. Proposals are due March 3,1980.
1980	
Feb. 13, 1980	Dr. F.A. Speer, manager of the High Energy Astronomy Observatory program at Marshall Space Flight Center, is named manager of the space telescope project for Marshall.
Feb. 21, 1980	NASA Associate Administrator Dr. Thomas A. Mutch informs Congress that the space telescope can be completed within its "originally estimated costs." NASA estimates space telescope development costs at $530 million, with another $600 million allotted for operation of the system over a 17-year period. Mutch says progress toward launch in December 1983 "continues to be excellent."
May 29, 1980	NASA announces the selection of Ford Aerospace to negotiate a contract for overall system design engineering on preliminary operations requirements and the test support system for the space telescope.
Sept. 18, 1980	NASA officials admit to space telescope cost and schedule problems in hearing before the House Science and Technology subcommittee.
1981	
Jan. 6, 1981	A.M. Lovelace, NASA associate administrator/general manager, submits a revised space telescope cost and schedule estimate. The launch period is revised to the first half of 1985, and the estimated development cost at launch is $700 million to $750 million (in 1982 dollars).

Table 4–50 continued

Date	Event
Jan. 16, 1981	NASA selects AURA for final negotiation of a contract to establish, operate, and maintain the Space Telescope Science Institute. It will be located at Johns Hopkins University. The contractor's estimate of the cost of the 5-year contract is $24 million, plus additional funds to support a guest observer and archival research program.
April 29, 1981	Perkin-Elmer completes polishing of the 2.4-meter primary mirror (see events dated November 1990).
April 30, 1981	Goddard Space Flight Center awards the contract for the management of the Space Telescope Science Institute to AURA. The period of performance for the $40.4 million contract extends through 1986. The institute will be located at Johns Hopkins University.
Oct. 23, 1981	Space telescope's "main ring" is delivered to Perkin-Elmer Corp. from Exelco Corp., which fabricated the ring over a period of 18 months.
Dec. 10, 1981	Perkin-Elmer finishes putting an aluminum coating 3 millionths of an inch thick on the primary mirror.
1982	
Jan. 26, 1982	Congress increases space telescope funding by $2 million to $121.5 million.
March 1982	The Critical Design Review of the space telescope's support systems module is completed, and the design is declared ready for manufacturing.
March 28, 1982	A report from the House Appropriations Committee states that the space telescope would cost $200 million more and reach orbit a year later than expected because of difficulties in development. The report blames delays and cost overruns on NASA for understaffing the program by 50 percent in its early development and on Perkin-Elmer for failing to properly plan for a project of the technical and manufacturing difficulty of the space telescope. Also, unremovable dust on the primary mirror after 15 months in a Perkin-Elmer "clean room" had lowered its reflecting power by 20 to 30 percent.
1983	
Feb. 4, 1983	NASA Administrator Beggs tells the House Science and Technology Committee that technical problems in developing the electronics and guidance and pointing system of the optical telescope assembly of the space telescope will delay the launch of the telescope and increase costs.
March 24, 1983	NASA Administrator Beggs tells House subcommittee that the space telescope has problems in a number of areas—the latching mechanism, the fine guidance sensor system, and the primary mirror—that are likely to result in cost overruns of $200 million or more and at least a 12- to 18-month delay. Beggs says that the primary mirror is coated with dust after sitting in a clean room for a year and may not be able to be cleaned without harming its surface. Its capability could be limited to 70 or 80 percent.

Table 4–50 continued

Date	Event
March 25, 1983	The preliminary report by the Investigations and Survey Staff of the House Appropriations subcommittee states that the space telescope will overrun its costs by $200 million, boosting its overall cost to $1 billion.
April 13, 1983	NASA names James B. Odom as manager of Marshall Space Flight Center's space telescope project.
April 26, 1983	James Welch, NASA's director of space telescope development, states that NASA may accept the dirty primary mirror because a current study indicates that the mirror would be within the acceptable range and would meet the original specifications in the contract. Also, NASA has decided to coat the sticking latching mechanism with tungsten carbide rather than redesign it.
June 15, 1983	Dr. William Lucas, Marshall Space Flight Center director, tells the House Space subcommittee that NASA estimates that telescope project costs will increase $300 million to $400 million to approximately $1.1 billion to $1.2 billion, and it expects to be able to launch in June 1986. He states that technical problems "are now understood and resolution is in hand."
June 15, 1983	Administrator Beggs acknowledges that, in retrospect, NASA made some errors in planning and running the space telescope program, but that the instrument has not been compromised.
Oct. 5, 1983	The space telescope is officially renamed the Edwin P. Hubble Space Telescope.
Nov. 17, 1983	NASA submits a report to Congress on proposed action that would augment efforts planned for the space telescope development by $30.0 million above the authorized and appropriated amount, for a revised FY 1984 level of $195.6 million.
Dec. 22, 1983	Space telescope officials are cautiously optimistic that the serious problems that surfaced on the space telescope over the last year have been solved and that the instrument can be launched on schedule in 1986.
1984	
April 2, 1984	The estimated cost of the space telescope has risen to $1.175 million. NASA Administrator Beggs states that Lockheed will lose some of its award fees because of poor workmanship problems.
April 30, 1984	NASA reports that tests of the fine guidance sensors have demonstrated that the telescope will meet stringent pointing and tracking requirements.
May 14, 1984	The idea surfaces of refurbishing the space telescope in space.
May 31, 1984	The five science instruments to fly on the space telescope complete acceptance testing at Goddard Space Flight Center: high-resolution spectrograph, faint-object spectrograph, wide-field/planetary camera, faint-object camera, high-speed photometer.
July 12, 1984	Technicians at Perkin-Elmer clean the primary mirror. NASA states that cleaning of the primary mirror has confirmed that the observatory will have the very best optical system possible.

Table 4–50 continued

Date	Event
Dec. 6, 1984	Goddard Space Flight Center's Telescope Operations Control Center satisfactorily conducts command and telemetry tests with the Hubble Space Telescope at Lockheed Missile and Space Corporation. This is the first of seven assembly and verification tests.
1985	
Jan. 17–18, 1985	A workshop by the Space Telescope Science Institute is held to give scientists an opportunity to present their recommendations for key projects for the space telescope.
Feb. 1, 1985	The National Society of Professional Engineers presents an award to Perkin-Elmer Corp. for its development of the Hubble Space Telescope's optical telescope assembly.
July 8, 1985	Lockheed Missiles and Space Co. reports that it has completed assembly of the primary structure for the Hubble Space Telescope.
July 19, 1985	Goddard Space Flight Center releases the RFP for design and fabrication of an Imaging Spectrograph for the space telescope. Proposals are due September 17.
Dec. 5, 1985	NASA selects three scientific investigations for the space telescope to lead to the development of one or two advanced scientific instruments for Hubble.
1986	
Jan. 26, 1986	The destruction of *Challenger* delays the launch of Hubble and other missions.
Feb. 27, 1986	Hubble completes acoustic and dynamic and vibrational response tests. The tests indicate that it can endure the launch environment.
May 2– June 30, 1986	Thermal-vacuum testing is conducted.
May 21, 1986	The last elements of Hubble—the solar arrays—are delivered to Lockheed Missiles and Space Co. (Sunnyvale, California) for integration into the main telescope structure.
May 27, 1986	Hubble successfully completes the thermal-vacuum testing in the Lockheed thermal-vacuum chamber.
Aug. 7, 1986	NASA and the Space Telescope Science Institute in Baltimore announce that 19 U.S. amateur astronomers will be allowed to make observations with Hubble. This decision is to show gratitude to the amateur astronomers for their help with telescopes for the last 400 years.
Aug. 8, 1986	Hubble successfully completes 2 months of rigorous testing.
1987	
March 17, 1987	Hubble starts a 3-day ground system test involving the five instruments that will be carried on board: wide field and planetary camera, high-resolution spectrograph, faint object spectrograph, high-speed photometer, and faint object camera.
Aug. 31– Sept. 4, 1987	Goddard Space Flight Center's Space Telescope Operations Control Center, Marshall Space Flight Center, and the Space Flight Telescope Science Institute conduct a joint orbital verification test.

Table 4–50 continued

Date	Event
Sept. 9, 1987	Hubble completes the reevaluation of Failure Mode and Effects Analysis (FMEA). This reevaluation of the FMEA/Critical Items List/hazard analysis is directed by the Space Telescope Development Division as part of NASA's strategy to return the Space Shuttle to flight status.
1988	
Feb. 10, 1988	Fred S. Wojtalik is appointed manager of the Hubble project at Marshall Space Flight Center.
March 31, 1988	The draft Program Approval Document for Hubble is completed. The draft contains the objectives of Hubble, the technical plan, including the experiments and descriptions, and the systems performance requirements.
June 20, 1988	NASA begins the fourth ground system test (GST-4) of Hubble. This will be the longest ground test to date, lasting 5 1/2 days, and also the most sophisticated because all of the six instruments will be used in their various operational modes; the new instrument is the fine-guidance astrometer.
July 24, 1988	Hubble completes the GST-4 tests successfully, except for a timing incompatibility between the science instruments and the computer. The problem is to be corrected by adjusting the software.
August 31, 1988	NASA delays launch of Hubble from June 1989 to February 1990.
1989	
July 19, 1989	The Space Telescope Science Institute completes its selection of the first science observation proposals to be carried out using Hubble. Among the 162 accepted proposals (out of 556 submitted) are plans to search for black holes in neighboring galaxies, to survey the dense cores of globular star clusters, to better see the most distant galaxies in the universe, to probe the core of the Milky Way, and to search for neutron stars that may trigger bizarre gamma-ray bursts.
Oct. 1989	A modified Air Force C-5A Galaxy transports the Hubble Space Telescope from Lockheed in California to its launch site at the Kennedy Space Center in Florida.
1990	
Jan. 19, 1990	NASA delays the Hubble launch to replace O-rings.
Feb. 5–7, 1990	Confidence testing is held.
Feb. 10, 1990	End-to-end communications test run using Tracking and Data Relay Satellite-East is concluded to interconnect the payload interfaces of *Discovery* in its hangar, Hubble in the Vertical Processing Facility, and the Space Telescope Operations Control Center at Goddard Space Flight Center.
Feb. 13, 1990	The final confidence test is held.
Feb. 15, 1990	Closeout operations begin.
Feb. 17, 1990	Functional testing of Hubble's science instruments is completed.
March 29, 1990	Hubble is installed in the Space Shuttle orbiter *Discovery*'s payload bay.
April 24, 1990	Hubble is launched on STS-31.

Table 4–50 continued

Date	Event
June 21, 1990	Hubble's project manager announces the telescope's inability to focus properly.
July 2, 1990	The Hubble Space Telescope Optical Systems Board of Investigation is formed under the chairmanship of Dr. Lew Allen of the Jet Propulsion Laboratory.
Oct. 16, 1990	Responsibility for the Hubble project (except for the optical system failure questions) is transferred from Marshall to Goddard.
Nov. 1990	The Board of Investigation releases findings, which conclude that a spherical aberration was caused by a flawed measuring device that was used to test the primary mirror at the manufacturer's facility.
Dec. 2, 1993	The Hubble Repair Mission on STS-61 installs corrective lenses and replaces solar panels.

Table 4–51. Ulysses Historical Summary

	Spacecraft	**Launch Vehicle/ Upper Stage**	**Launch Date**
October 1978 Project Start	1 NASA spacecraft 1 ESA spacecraft	Single STS/IUS (3-stage launch)	1983 launch
April 1980		Split launches: 1 NASA, 1 ESA	Launch deferred to 1985
February 1981	NASA spacecraft "slowdown"	Launch vehicle changed to STS/Centaur	Launch deferred to 1986
September 1981	U.S. spacecraft canceled		
January 1982		Launch vehicle changed to STS/IUS (2-stage)	
July 1982		Launch vehicle changed to STS/Centaur	
January 1986		*Challenger* accident	Launch deferred indefinitely
June 1986		STS/Centaur program canceled	
November 1986		IUS/PAM-S upper stage procurement decision	
			Launch date selected: October 1990