Chapter Two

NASA and Planetary Exploration

by Amy Paige Snyder

Prelude to NASA's Planetary Exploration Program

Four and a half billion years ago, a rotating cloud of gaseous and dusty material on the fringes of the Milky Way galaxy flattened into a disk, forming a star from the innermost matter. Collisions among dust particles orbiting the newly-formed star, which humans call the Sun, formed kilometer-sized bodies called planetesimals which in turn aggregated to form the present-day planets.[1] On the third planet from the Sun, several billions of years of evolution gave rise to a species of living beings equipped with the intellectual capacity to speculate about the nature of the heavens above them.

Long before the era of interplanetary travel using robotic spacecraft, Greeks observing the night skies with their eyes alone noticed that five objects above failed to move with the other pinpoints of light, and thus named them *planets*, for "wanderers."[2] For the next six thousand years, humans living in regions of the Mediterranean and Europe strove to make sense of the physical characteristics of the enigmatic planets.[3] Building on the work of the Babylonians, Chaldeans, and Hellenistic Greeks who had developed mathematical methods to predict planetary motion, Claudius Ptolemy of Alexandria put forth a theory in the second century A.D. that the planets moved in small circles, or epicycles, around a larger circle centered on Earth.[4] Only partially explaining the planets' motions, this theory dominated until Nicolaus Copernicus of present-day Poland became dissatisfied with the inadequacies of epicycle theory in the mid-sixteenth century; a more logical explanation of the observed motions, he found, was to consider the Sun the pivot of planetary orbits.[5]

1. For a detailed description of the evolution of the solar system and individual planets, moons, and other bodies, see David Morrison and Tobias Owen, *The Planetary System* (New York, NY: Addison-Wesley, 1987). J. Kelly Beatty and Andrew Chaikin, eds., *The New Solar System* (Cambridge, MA: Sky Publishing Corporation, 1990) is a comprehensive guide to solar system bodies, their properties, and their postulated evolutionary histories.

2. Without the aid of telescopes, Mercury, Venus, Mars, Jupiter, and Saturn were the only planets visible from Earth, which then was not known to be a planet as well. Interestingly, all of the planets are named for Roman gods with the exception of Uranus, who was a Greek god.

3. For an excellent history of planetary studies leading up to and including the inception of NASA, see Ronald A. Schorn, *Planetary Astronomy: From Ancient Times to the Third Millennium* (College Station, TX: Texas A&M University Press, 1998). William Sheehan, *Worlds in the Sky: Planetary Discovery from Earliest Times through Voyager and Magellan* (Tucson, AZ: University of Arizona Press, 1992) describes the history of human study and knowledge of individual planets and other solar system targets.

4. Although Ptolemy is credited with the development of epicycle theory, Hipparchus was also responsible for its rise.

5. Copernicus' treaty, *De Revolutionibus Obrium Caelestium* (1543) was banned by the Catholic Church for nearly two hundred years beginning in 1616 due to its "heretical" idea of removing Earth from the universe's center. See Thomas S. Kuhn, *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* (Cambridge, MA: Harvard University Press, 1957) for more on Copernicus' contributions. It should be noted that the Grecian Aristarchus of Samos had proposed that Earth and the other planets revolved around the Sun even before Ptolemy put forth the theory of epicycles.

During the next 150 years, Johannes Kepler of Denmark deduced that planets moved around the Sun in elliptical orbits, and Isaac Newton of England identified the force that yielded these orbits and interactions between planetary bodies as gravity.[6]

By the early seventeenth century, people no longer had to rely only on their eyesight to study the heavens—the refractor telescope, comprised of glass lenses—made its debut in 1609 and thus marked the start of a new era of planetary discovery. Though not the very first to scan the night sky with a telescope, Italian mathematician Galileo Galilei worked hardest to perfect his refractors (his best telescope achieved a magnifying power of thirty) and reported details of the Moon's surface features, observed the phases of Venus, and discovered the four largest satellites of Jupiter. As subsequent generations of astronomers worked to improve the power of refractors, they had to build increasingly lengthy telescopes, separating the eyepiece from the objective lens, to combat the distortion in colors that occurred in telescopes with wider objective lenses. Newton's invention of the reflector telescope, which used a curved mirror in lieu of glass lenses, was not limited by this problem. Observatories throughout the Western world installed larger and more powerful telescopes of both types as they improved in capability over the next several centuries. The developments in telescopes led to the discovery of three more planets in the solar system—Uranus, Neptune, and Pluto—as well as numerous moons, asteroids, and comets previously unseen by the unaided eye.[7]

During the nineteenth century, the United States emerged as a player in the field of planetary astronomy. In 1840, New York University Professor John William Draper photographed the Moon for the first time, while William Cranch Bond used the 15-inch refractor at the Harvard College Observatory to discover satellites and rings around Saturn in 1848. But while American facilities like the Harvard College Observatory focused on visual studies of the planets during the nineteenth century, many of them turned their attention to stellar research by the turn of the century. With the advent of more powerful telescopes came the desire among many astronomers to look beyond the solar system and farther into the reaches of space. In addition to better telescopes came advances in photography and spectroscopy—techniques that were helpful to planetary astronomy to some extent but proved more appropriate to the study of more distant objects in the universe.[8] Developments in the theories of quantum mechanics, relativity, and cosmology further sparked interest in astrophysics rather than planetary studies. By the turn of the century, visual planetary astronomy was becoming a subject in actual disrepute, as when wealthy astronomer Percival Lowell made highly-publicized yet inaccurate claims that apparent lines streaking the surface of Mars were irrigation canals constructed by intelli-

6. Newton's famous work on gravity and other physical principles is *Philosophiae Naturalis Principia Mathematica* (1687).

7. For more on the development of the telescope, see Henry C. King, *The History of the Telescope* (London, England: Charles Griffin, 1955).

8. When used to record details on planets' surfaces, time-exposure photographic plates tended to register only blurs due to the atmosphere's movement, indicating that the human eye was still the better instrument for recording physical features. Spectroscopy was also more applicable to stellar astronomy, as the chemical elements producing spectral lines were easier to identify for stars and nebulae than for planets.

gent inhabitants.[9] By the early twentieth century, with many observatories following tacit rules that planetary studies could occupy no more than 10 percent of telescope time, astronomers had practically abandoned the objects that were once the focus of celestial studies.

The drought in U.S. solar system studies came to an end with the nation's experience in World War II.[10] Astronomers and other scientists with backgrounds in physics played a major role in the development of radar, instrumentation to explore infrared wavelengths, and means to better forecast weather. In addition to yielding new techniques useful to planetary astronomy, these efforts served the nation well in fighting the war; in return, the government increased its patronage of scientific studies across many disciplines, including all areas of astronomy. The war also gave rise to rocket and missile technology, advanced mainly by the Germans but then exploited by the victorious Allies. Bringing home leftover V-2 rockets and leading German rocket engineers, American military forces quickly went to work to study the technology of the vehicles that would soon forever change the way people understood the solar system.

The military's interest in the utility of planetary studies continued even after the war. The Army, Navy, and Air Force conducted and funded a number of projects and even built new observatories to perform planetary research to further their understanding of meteorology and radar. As early as 1946 the Army studied the Moon's thermal radiation using radar equipment, whose improvement led to more precise determination of distances to the planets and the nature of their surface features.[11] The Naval Research Laboratory began planetary radio astronomy work in 1947 to gather data on the Sun's radio emission as well as infrared radiometric properties of the planets, while the Office of Naval Research supported planetary work at several universities.[12] In an effort to better understand weather patterns and the atmosphere of Earth, the Air Force funded a project at Lowell Observatory to examine global atmospheric circulation on other planets and also erected a solar observatory in New Mexico to investigate the Sun's impact on Earth's atmosphere and ionosphere.[13] In addition to the scientific studies, the Army and Air Force both engaged in projects to develop rockets and satellites capable of traveling to the Moon and planets for both

9. As had others, Lowell mistakenly interpreted the *canali* ("channels") on Mars described by Italian astronomer Giovanni Schiaparelli as engineered waterways. Beginning in 1895 he published a series of books and articles based on this belief, including *Mars* (1895), *Mars and Its Canals* (1906), and *Mars as an Abode for Life* (1908). Although Lowell's writings incurred the scorn of many astronomers, he left a great legacy to planetary science in the Lowell Observatory, which he founded in Flagstaff, Arizona, for the primary purpose of planetary studies. The observatory became more reputable after Lowell's death in 1916 and with the discovery of Pluto there by Clyde Tombaugh in 1930. See William Graves Hoyt, *Lowell and Mars* (Tucson, AZ: University of Arizona Press, 1976) for more details.

10. See Ronald E. Doel, *Solar System Astronomy in America: Communities, Patronage, and Interdisciplinary Science, 1920–1960* (Cambridge, England: Cambridge University Press, 1996) for an excellent account of planetary studies performed between the end of World War I and the inception of NASA.

11. John H. DeWitt and E. King Stodola, "Detection of Radio Signals Reflected from the Moon," *Proceedings of the Institute of Radio Engineers* 37 (1949): 229–42. For a thorough examination of planetary radar astronomy, see Andrew J. Butrica, To See the Unseen: A History of Planetary Radar Astronomy (Washington, DC: NASA Special Publication (SP)-4218, 1996).

12. Joseph N. Tatarewicz, S*pace Technology and Planetary Astronomy* (Bloomington, IN: Indiana University Press, 1990), p. 16; Doel, *Solar System Astronomy in America,* pp. 192–93, 236–40.

13. The major results of the Lowell Observatory project can be found in Earl C. Silpher et al., "The Study of Planetary Atmospheres: Final Report," US Air Force Contract AF 19(122)–162, Lowell Observatory, September 30, 1952.

military and peaceful purposes.[14] Responding to the project needs of the military, a number of commercial aviation firms also moved into the business of space vehicle and spacecraft development, which made the prospects of interplanetary travel even more realistic.

Indeed, advances in space technology and newly perceived advantages to knowing about the solar system had rekindled U.S. interest in the field of planetary science by the mid-1950s. Some astronomers distinguished for their work in stellar astronomy turned their attention to targets closer to home. Perhaps the most renowned, Gerard Kuiper of the University of Chicago, who researched double stars and stellar evolution before the war, used infrared spectrometry to confirm the presence of carbon dioxide in Mars' atmosphere and water at the polar caps in 1948.[15] Between 1953 and 1963, Kuiper compiled a photographic atlas of the Moon as well as a comprehensive, four-volume summary of human knowledge of the solar system.[16] During the decade, American as well as international astronomers also created organizations to plan and discuss research in planetary astronomy. The Mars Committee, for example, consisted of scientists that met annually to share the results of their observations of the Red Planet.[17] Even popular literature reflected the new preoccupation with the planets, with writers—including scientists and engineers—conveying to the public in simple words modern understanding of the solar system and their vision of human exploration of neighboring worlds.[18] Little did solar system enthusiasts know that before the next decade, national efforts in planetary astronomy would come together under a single organization and begin a new paradigm of operation as a reaction to a stunning space feat performed halfway around the world.

---

14. In 1952, top German rocket engineer Wernher von Braun expounded his vision of interplanetary vehicles that would transport humans to the surface of the Red Planet in Wernher von Braun, *The Mars Project*, English translation prepared by Henry J. White (Urbana, IL: University of Illinois Press, 1953). For Air Force space technology activities, see Nick A. Komans, *Science and the Air Force: A History of the Air Force Office of Scientific Research* (Arlington, VA: Office of Aerospace Research, 1966) and David N. Spires, *Beyond Horizons: A Half Century of Air Force Space Leadership* (Washington, DC: U.S. Government Printing Office, 1997).

15. Gerard P. Kuiper, "Planetary Atmospheres and Their Origin," in Gerard P. Kuiper, ed., *The Atmospheres of Earth and Planets*, 2nd ed. (Chicago, IL: University of Chicago Press, 1952), pp. 358–60.

16. Gerard P. Kuiper, ed., *Photographic Lunar Atlas: Based on Photographs Taken at the Mount Wilson, Lick, Pic du Midi, McDonald, and Yerkes Observatories* (Chicago, IL: University of Chicago Press, 1960); Gerard P. Kuiper, ed., *The Sun* (Chicago, IL: University of Chicago Press, 1953); Gerard P. Kuiper, ed., *The Earth as a Planet* (Chicago, IL: University of Chicago Press, 1954; second impression, 1958); Gerard Kuiper and Barbara M. Middlehurst, eds., *Planets and Satellites* (Chicago, IL: University of Chicago Press, 1961); Barbara M. Middlehurst and Gerard P. Kuiper, eds., *The Moon, Meteorites, and Comets* (Chicago, IL: University of Chicago Press, 1963).

17. For more details on the Mars Committee's activities, see, for example, E. C. Silpher and A. G. Wilson, "Report on the Conference of the Mars Committee" (held at Lowell Observatory, October 22–23, 1953) and "Minutes of a Meeting of the Mars Committee Held at the Headquarters of the National Geographic Society."

18. Examples of popular books on planetary exploration written in the 1950s include Willy Ley, *The Conquest of Space* (New York, NY: Viking Press, 1949); Joseph Kaplan, et al., *Across the Space Frontier* (New York, NY: Viking Press, 1952); Cornelius Ryan, ed., *Conquest of the Moon* (New York, NY: Viking Press, 1953); and Willy Ley and Wernher von Braun, *The Exploration of Mars* (New York, NY: Viking Press, 1956). The history of popular interest in Mars can be found in Martin Caidin and Jay Barbree, with Susan Wright, *Destination Mars: In Art, Myth, and Science* (New York, NY: Penguin Putnam, 1997). For more details on public interest in space exploration see Howard McCurdy, *Space and the American Imagination* (Washington, DC: Smithsonian Institution Press, 1997). McCurdy argues that human rather than robotic space exploration has been the predominant focus of imagination throughout history, and for this reason human space travel became the emphasis in the U.S. civil space program.

A Federal Home for Planetary Science

Both the United States and the Soviet Union had pledged to develop and launch scientific Earth satellites during 1957 and 1958 for the International Geophysical Year.[19] In addition to improving understanding of Earth's atmosphere and its relationship to the Sun during this worldwide research effort, the nations hoped to demonstrate the feasibility of launching and orbiting around Earth spacecraft that could serve scientific as well as other purposes. Prior awareness of the Soviet Union's project, however, did not placate the American public when news spread in October 1957 that the Communist nation had succeeded in lofting into orbit a beeping, basketball-sized satellite known as Sputnik. In reaction to the Soviet achievement, government and military officials quickly made plans to mobilize a major national space effort.

Solar system exploration played a significant role in the nation's earliest attempts to outdo the Soviet Union in space.[20] The first such scheme was put forth just three weeks after Sputnik's launch by William Pickering, director of the Jet Propulsion Laboratory (JPL). Calling his proposal Project Red Socks, Pickering envisioned sending robotic probes to the Moon.[21] Though the probes would be equipped with scientific payloads, Project Red Socks' main purpose was to demonstrate the United States' capability to reach Earth's satellite and travel beyond. Early in 1958, the Advanced Research Projects Agency (ARPA), which then had responsibility for the nation's space projects, considered the proposal. By March, Secretary of Defense Neil McElroy announced that the United States would attempt to send robotic envoys to explore up-close another body in the solar system.[22] [II-1, II-2]

Under the direction of ARPA, the Air Force, the Army, and JPL immediately went to work to develop the hardware for the project, renamed Pioneer. Some have argued that the differences between the two military branches' approaches to Pioneer doomed the project in its planning stages.[23] Whether actually due to such differences or simply to the fact that space launch was a very new activity, Project Pioneer encountered one failure after the next. An explosion of its Thor-Able launcher shortly after liftoff on

---

19. James C. Hagerty, The White House, "IGY Statement," July 29, 1955. This document appears as I-17 in John M. Logsdon, gen. ed., with Linda J. Lear, Jannelle Warren-Findley, Ray A. Williamson, and Dwayne A. Day, *Exploring the Unknown: Selected Documents in the History of the U.S. Space Program, Volume I: Organizing for Exploration* (Washington, DC: NASA SP-4407, 1995), pp. 200–01.

20. Two books authored by leaders of NASA's early space science program are particularly valuable in providing a comprehensive, inside look at the development of NASA's space science program. These books are Homer E. Newell, *Beyond the Atmosphere: Early Years of Space Science* (Washington, DC: NASA SP-4211, 1980) and John E. Naugle, *First Among Equals: The Selection of NASA Space Science Experiments* (Washington, DC: NASA SP-4215, 1991).

21. Jet Propulsion Laboratory, *Project Red Socks* (Pasadena, CA: Jet Propulsion Laboratory, California Institute of Technology, October 21, 1957), pp. 2–3; William Pickering to Lee DuBridge, with attachments, October 25, 1957. Unless otherwise noted, all unpublished documents cited in this essay may be found in the NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC. Founded in 1936 as the Guggenheim Aeronautical Laboratory of the California Institute of Technology, JPL started as a rocketry research and development center operated by the California Institute of Technology under contract from the Army Ordnance. The center began tinkering with space probes after World War II.

22. Roy Johnson, ARPA Director, to Commanding General of Ballistic Missiles Div, ARDC, "Order to Proceed with Development of Three Lunar Probes," March 27, 1958; U.S. Army Ordnance Missile Command, "Development and Funding Plan for Project One, ARPA Order 1–58, as Amended," May 15, 1958.

23. Edward Clinton Ezell and Linda Neuman Ezell, *On Mars: Exploration of the Red Planet, 1958–19*78 (Washington, DC: NASA SP-4212), p. 25.

August 17, 1958, prevented the first lunar probe from even passing through Earth's atmosphere. Two months later Pioneer 1 was successfully launched and returned data on near-Earth space, but failed to reach the Moon because its second stage shut down prematurely. Pioneer 2 failed when its booster's third stage failed to ignite. While Pioneer 3 traveled away from Earth for 38 hours and discovered a second Van Allen belt of trapped energetic particles around Earth, it failed to arrive at its lunar target when the Jupiter launcher's first stage cut off prematurely. By the time Pioneer 4 was launched in March 1959, passing too far from the Moon to use its scanning instruments, the Soviets had already successfully flown Luna 1 by the Moon and would soon crash-land a second Luna on the Moon's surface. Three more Pioneers failed by 1960, and the project came to an unsuccessful end.[24]

As plans for Project Pioneer were getting underway, President Eisenhower proposed to Congress in April 1958 the creation of a civilian agency to begin handling the nation's activities in space. A peaceful approach to space operations, the President reasoned, was preferable in the eye of the national and global publics to allowing the military to continue responding to the Soviet space challenge.[25] Receiving congressional support for this proposal, Eisenhower approved the law establishing the National Aeronautics and Space Administration (NASA), which began operations on October 1, 1958.[26] From that point onward, the new agency was responsible for national programs of human spaceflight, passive communications, meteorology, aeronautics research, and space science.[27]

Not specifying particular space science disciplines or projects that NASA should pursue, the space agency's enacting legislation only noted an obligation regarding "the expansion of human knowledge of phenomena in the atmosphere and space."[28] This language gave NASA the responsibility to decide how it would design its space science program. Soliciting the advice of scientists renowned in a variety of fields, the agency began within its first few months to assemble a space science program that would lead to greater understanding of the Earth and the cosmos by conducting investigations with spacecraft as well as ground-based facilities.[29] With scientists expressing great interest in making solar system exploration part of the national space science effort, NASA managers began planning at once for a repertoire of missions that would travel into deep space.

While space science enthusiasts had little difficulty reaching the decision to make solar system studies a scientific priority, arriving at a consensus on where to go first proved formidable. It became clear early on that NASA officials, scientists, and even spacecraft engineers made a distinction between lunar and planetary exploration. With the Soviets aiming for the Moon, NASA's top administrators could not resist making a successful robotic visit to the Moon and its environs its first priority in the area of solar system explo-

---

24 In 1965, NASA revived Project Pioneer. The new series of Pioneer spacecraft complemented interplanetary data returned from the Mariner probes.

25. Alison Griffith, *The National Aeronautics and Space Act: A Study of the Development of Public Policy* (Washington, DC: Public Affairs Press, 1962), pp. 100–01; Newell, Beyond the Atmosphere, pp. 88–89.

26. NASA grew out of the National Advisory Committee for Aeronautics, which had been established in 1915. "National Aeronautics and Space Act of 1958," Public Law 85–568, 72 Stat., 426. Signed by the president on July 29, 1958.

27. Newell, *Beyond the Atmosphere,* pp. 95–101. The military retained authority over active communications and reconnaissance. Responsibility for several other relevant areas, such as launch vehicle development, was left to NASA and the Department of Defense to arrange.

28. "National Aeronautics and Space Act of 1958," Sec. 102(c)(1).

29. Newell, *Beyond the Atmosphere,* pp. 100–15.

ration. As the next section of this essay reveals, NASA pursued scientific exploration of the Moon with great vigor from the start, putting this goal ahead of sending spacecraft to the planets. An important first step in succeeding in this effort, however, was for the space agency to make clear its interests and delineate its authority in making such decisions to JPL, which had been transferred from the Army to NASA by executive order in December 1958.[30] Destined to become NASA's premier facility for managing solar system exploration missions, JPL preferred to bypass the Moon and take on the challenge of sending probes to worlds beyond the Earth-Moon system.

Believing that beating the Soviets to Venus or Mars would be a loftier triumph than reaching the Moon, JPL managers and engineers began thinking about solar system exploration missions NASA could perform—even before the Center was officially transferred to the agency. Interpreting a memo from NASA's Office of Space Flight Development Director Abe Silverstein asking JPL to consider future space projects as a request to devise a long-range program for the agency, JPL developed a preliminary five-year plan of solar system exploration in November 1958.[31] By April 1959, JPL scientists produced a final report that addressed detailed aspects of sending spacecraft to the planets. JPL advised taking every possible opportunity to send probes to Mars and Venus, while filling in the "down time" with missions to the Moon, launching them on Atlas-Vega and Saturn 1 boosters. The researchers also suggested that NASA undertake a complementary program of ground-based planetary studies.[32] [II-5]

JPL's report clearly expressed the Center's desire to focus on planetary missions, with lunar exploration as a secondary goal. But NASA had opted by mid-1959 to concentrate on lunar exploration as its venue of competition with the Soviets and to reject JPL's plans to develop probes bound for Mars and Venus, piquing Pickering's concern about JPL's involvement with the space agency. That December, officials from NASA Headquarters and JPL exchanged correspondences concerning JPL's role in planning and management of the solar system exploration program.[33] [II-6] On December 28, a delegation from NASA Headquarters visited JPL to discuss plans for solar system exploration and to better define the responsibilities of the two entities in mission planning and execution.

By the end of the meetings, the attendant officials resolved that NASA Headquarters would remain responsible for overall program planning, while JPL would lead the engineering and execution of lunar and planetary missions—a position that it has maintained for the most part through the present.[34] NASA officials assured JPL that while lunar exploration remained the agency's main area of solar system interest, planetary work would get underway soon, with launches to Mars and Venus when-

---

30. For more on JPL's involvement with NASA, see Clayton R. Koppes, *JPL and the American Space Program: A History of the Jet Propulsion Laboratory* (New Haven, CT: Yale University Press, 1982); Newell, Beyond the Atmosphere, pp. 258–73.

31. John F. Froehlich, "Minutes of Meeting on N.A.S.A. Space Program of October 27, 1958," October 28, 1958; R. Newburn and M. Neugebauer, "Preliminary Consideration of a Limited Class of Problems Suitable for Study by Interplanetary Probes and / or Satellites," November 13, 1958.

32. Albert R. Hibbs, ed., "Exploration of the Moon, Planets, and Interplanetary Space" (Pasadena, CA: JPL Technical Report 30–1, April 30, 1959).

33. Richard Horner to William Pickering, December 16, 1959; William Pickering to Abe Silverstein, December 17, 1959; Abe Silverstein to William Pickering, December 21, 1959.

34. NASA General Management Instruction 2–2–11, "NASA-JPL Relationships," August 2, 1960.

ever they were in "optimum position for a planetary mission." A NASA ten-year plan created just days before the meeting had already affirmed the agency's commitment to studying the planets.[35] Finally, NASA pledged to create a single working committee for lunar and planetary exploration in the NASA management structure.[36] [II-7] Soon thereafter, Homer Newell, assistant director for space sciences and one of the Headquarters delegates on the trip, created the Lunar and Planetary Programs Office, to be headed by NASA officials but staffed by outside scientists, to recommend to NASA what projects the agency should undertake. As Newell noted years after he left NASA, although the NASA-JPL entanglement required the two entities to wrestle with "knotty issues in human relations," the JPL staff was instrumental in "laying the groundwork for the phenomenal successes that were later achieved in investigating [both] the [M]oon and planets."[37]

While getting scientific instruments into space became the focus of NASA's solar system exploration program, supporters of planetary and lunar studies pushed the agency to fund ground-based planetary astronomy as well. With scientists still having much to learn about the solar system, planetary enthusiasts argued that a strong ground-based program would serve as an economical way to gain knowledge of the planets needed to prepare spacecraft bound for neighboring worlds. Throughout the early years of NASA's existence, military, commercial, and non-profit groups with interest in the budding space program completed studies on the feasibility and importance of a federally funded, ground-based planetary program.[38] In June 1960, the topic of ground-based observatories became the focus of a Space Science Board conference on planetary atmospheres, where some of the attendees passed a resolution that the Board recognize the importance of federal support for ground-based planetary research.[39] That same month, Kuiper, by then a consultant to NASA's Lunar and Planetary Program Office, stressed a ground-based program's merit, expressing to Newell that a ground program was "not merely a matter of economy," but also "a logical necessity" for obtaining an "integrated" understanding of the data.[40] [II-8] The following year, National Academy of Sciences President Lloyd Berkner sent to NASA Administrator James Webb the Board's recommendation that NASA fund a strong program of both space and ground space science research.[41]

The urging of these groups that NASA support a ground-based planetary astronomy program came to fruition almost as soon as they voiced their desires, as NASA immediately

---

35. NASA, Office of Program Planning and Evaluation, "The Ten Year Plan of the National Aeronautics and Space Administration," December 16, 1959.

36. Homer Newell, memo to file, "Trip Report for the Visit to the Jet Propulsion Laboratory on December, 28, 1959 by Homer E. Newell, Jr., Newell Sanders, J. A. Crocker, Morton J. Stoller," December 30, 1959, pp. 1–3.

37. Newell, *Beyond the Atmosphere*, p. 259.

38. For a more detailed description of the evolution of federally supported, ground-based planetary studies, see Joseph N. Tatarewicz, *Space Technology and Planetary Astronomy* (Bloomington, IN: Indiana University Press, 1990).

39. Space Science Board, "Minutes of the Eighth Meeting," June 25, 1960. NASA Deputy Administrator Hugh Dryden, who was present at the meeting, suggested to the Board that the resolution be passed along to President Kennedy's science advisor, George Kistiakowsky, to be considered as part of a new national science policy.

40. Gerard Kuiper to Homer Newell, "Need for a Ground-Based Lunar and Planetary Observatory," June 18, 1960.

41. Lloyd V. Berkner to James E. Webb, March 31, 1961; Space Science Board, "Support of Basic Research for Space Science," March 27, 1961.

began subsidizing new and current observatories and laboratories to study the solar system. One of NASA's earliest major contributions to ground-based solar system research was the funding of the University of Arizona's Lunar and Planetary Laboratory. In 1960, Kuiper relocated the lunar and planetary operations of the Yerkes Observatory to this new facility, which aimed to serve as a "research and teaching unit concerned with the study of the Moon and the planets."[42] Staff of the Laboratory have assisted in collecting and interpreting data from NASA's solar system exploration missions since the Laboratory's inception. Throughout the 1960s, NASA also funded upgrades of several ground-based telescopes to make them more suitable for planetary astronomy purposes. The space agency built an observatory on Mauna Kea in Hawaii that has specialized in planetary investigations. In addition, NASA began development in 1958 of the Deep Space Network—the first worldwide, civilian satellite communications network. Consisting of three radio antenna stations in California, Spain, and Australia, the Deep Space Network has the ability to continuously track robotic spacecraft and remains NASA's means for communicating with probes sent into the solar system.[43]

Within a few years of its inception, NASA had become the primary supporter and coordinator of solar system exploration activities in the United States. The creation of a national space agency equipped with millions of dollars of federal money for planetary and lunar projects and spurred by international competition provided the invigoration solar system astronomy needed to move forward after its decline in the early part of the twentieth century. Moreover, technological progress had equipped astronomers with the means not only to study but also to *explore* the solar system *in situ* with spacecraft, the "sine qua non" of space science.[44] Between NASA Headquarters, JPL, and the other NASA Field Centers, the federal government had created an institution that, beginning in the 1960s, transformed scientists' knowledge about the Moon and planetary system.

NASA Shoots for the Moon

While ARPA was striving to successfully deliver Pioneer spacecraft to the Moon's vicinity in the fall of 1958, Naval Research Laboratory theoretical physicist Robert Jastrow arrived at NASA Headquarters to head the agency's program of basic research in astronomy and planetary science. Within a short time he came across *The Planets: Their Origin and Development*, a 1952 book in which Nobel laureate Harold Urey put forth his theories of lunar evolution.[45] Fascinated by Urey's arguments that the Moon was geologically dead

---

42. Ewen A. Whitaker, *The University of Arizona's Lunar and Planetary Laboratory: Its Founding and Early Years* (Tucson, AZ: University of Arizona [sometime after August 1985]), p. 29. This document provides an excellent history of the Lunar and Planetary Laboratory.

43. The first components of the Deep Space Network were two antennas built by JPL in the Mojave Desert. These antennas were originally intended to track and receive telemetry from the military's Pioneer probes and to test the feasibility of long-range satellite communications. JPL later used the antennas for a ground-based Venus radar experiment. Butrica, *To See the Unseen*, pp. 36–38. For more on the Deep Space Network's history, see William R. Corliss, *A History of the Deep Space Network* (Washington, DC: NASA CR-151915, 1976); Nicholas A. Renzetti, ed., *A History of the Deep Space Network from Inception to January 1, 1969*, Vol. 1, JPL Technical Report 32–1533, September 1, 1971; and Craig B. Waff, "The Road to the Deep Space Network," *IEEE Spectrum* (April 1993): 53.

44. Newell, *Beyond the Atmosphere*, p. 133.

45. Harold C. Urey, *The Planets: Their Origin and Development* (New Haven, CT: Yale University Press, 1952). Urey, together with George M. Murphy and Ferdinand G. Brickwedde, won the Nobel Prize for Chemistry in 1934 for their discovery of the existence of heavy water, the molecules of which consist of an atom of oxygen and two atoms of heavy hydrogen or deuterium. For an overview of Urey's achievements, see Stephen G. Brush, "Nickel for Your Thoughts: Urey and the Origin of the Moon," *Science* 217 (1982): 891–98.

and that its interior recorded conditions of the early solar system, Jastrow contacted Urey to discuss the prospects for scientific exploration of the Moon. In January 1959, just after the Soviet Luna 1 had passed within 5000 kilometers of the Moon and the American Pioneer program had endured its third failure, Urey visited NASA Headquarters to share his views on lunar exploration's scientific value.[46] After talking together, Jastrow and Urey approached Newell about initiating a special effort to land on the Moon to catch up with the Soviets. Receptive to the idea, Newell asked Jastrow and Urey to draft a memo proposing that NASA institute a plan to crash-land spacecraft laden with scientific instruments on the Moon's surface over the next two years, with the goal of a soft lunar landing by 1961.[47] Serving as the first formal scientific rationale for lunar exploration, this memo proclaimed that NASA should undertake a program of lunar exploration in accordance with goals put forth by planetary scientists. Urey and Jastrow asserted in the memo, "It is our opinion that a study of the Moon is more important than a study of Venus or Mars, from the standpoint of the origin of the solar system."[48] [II-3]

During the course of 1959, NASA officials stirred by the Soviet Union's success in reaching the Moon took heed of the proposition and elevated lunar exploration to a very high priority of the national space program—putting it in a more prominent position than planetary exploration.[49] [II-4] Two meetings of the newly formed ad hoc Working Group on Lunar Exploration in February 1959 laid out the main lines of a proposed automated lunar program. In late May, Silverstein and Newell reprogrammed two Atlas-Vega flights as lunar orbiters; two months later Silverstein instructed JPL to cancel plans for some Venus and Mars missions and to redesign the Vega upper stage for a series of lunar orbiting missions.[50] By July, NASA Administrator T. Keith Glennan formally recommended to a group of top presidential advisors and security officials that the nation concentrate its solar system exploration program on the Moon because it best supported national security goals and was a more proximate, accessible target than the planets.[51] With the approval of Glennan's proposal, NASA Headquarters ordered JPL to cancel its January 1961 Venus mission, leaving the center to work only on lunar missions.[52]

NASA's lunar interest did not stop at orbiting science spacecraft around the Moon but extended to crashing them into its surface. At the very end of 1959, NASA Headquarters personnel asked JPL to begin planning for a hard lunar landing project.[53] Taking the name Ranger, the project would consist of two initial engineering flight tests that would perform experiments on fields and charged particles in Earth's upper atmos-

46. Robert Jastrow, *Journey to the Stars: Space Exploration—Tomorrow and Beyond* (New York, NY: Bantam, 1989), pp. 9–14.

47. Homer Newell, "Meeting of Harold Urey, Robert Jastrow, John O'Keefe, and Homer Newell," January 16, 1959. This meeting is recorded in the author's notebook.

48. Jastrow, *Journey to the Stars*, p.13; R. Cargill Hall, *Lunar Impact: A History of Project Ranger* (Washington, DC: NASA SP-4210, 1977), p. 15.

49. U.S. Congress, House, Committee on Science and Astronautics, *The First Soviet Moon Rocket*, Report of the Committee, 86th Cong., 1st sess., on H.R. 1086 (Washington, DC: Government Printing Office, 1959), p. 6; Newell to Silverstein, March 23, 1959.

50. William Pickering to Abe Silverstein, July 10, 1959, as cited in Hall, *Lunar Impact*, p. 20.

51. T. Keith Glennan, memorandum for the file, July 24, 1959, as cited in Hall, *Lunar Impact*, p. 20.

52. William Pickering to Abe Silverstein, August 4, 1959, as cited in Hall, *Lunar Impact*, p. 20.

53. Homer Newell, memo to file, "Trip Report for the Visit to the Jet Propulsion Laboratory on December, 28, 1959, by Homer E. Newell, Jr., Newell Sanders, J.A. Crocker, Morton J. Stoller," December 30, 1959.

phere and near-Earth space, and three subsequent spacecraft which would gather scientific data on the Moon before impacting it. NASA officials hoped Ranger would demonstrate the technology necessary for spacecraft bound for deep space as well as the abilities to deliver scientific payloads to a celestial target, position experiments, perform a proposed scientific program, and transmit the results to Earth.[54] Instruments planned for the crash landers included a television camera to return close-up photographs of the surface, a seismometer, a gamma-ray spectrometer to determine the surface's chemical composition, and radar for reflectivity measurements. Silverstein hoped JPL would complete the project in thirty-six months.[55]

The five originally scheduled Ranger missions did, in fact, make it off the launch pad within three years. All five, however, failed, preventing the return of virtually all of the planned science data. Booster failures and inaccurate launch trajectories contributed to the first three Ranger failures. Ranger 4 crashed without control on the far side of the Moon, while Ranger 5 experienced a power failure that ended the mission. NASA and JPL investigations of the series of Ranger failures revealed that failures specific to the spacecraft themselves resulted from the fact that the missions had become increasingly risky when engineers removed many of the spacecraft's redundant systems in an effort to meet the Atlas-Agena launch vehicle's weight limitations.[56] After a complete design review, changes in the project's management and development practices, and the addition of several redundant features, NASA attempted to send four more Rangers to the Moon. Ranger 6 launched in January 1964 and successfully reached the Moon, but failed to transmit any photographs from its six television cameras, leading NASA, JPL, and Congress to conduct further investigations into the management and engineering processes of JPL and the space agency.[57] The congressional report concluded that NASA Headquarters failed to provide enough oversight, while JPL did not adhere to NASA's directions.

The United States finally claimed a completely successful shot at the Moon on July 31, 1964, when Ranger 7 became the first American spacecraft to return meaningful data before striking the lunar surface. Returning more than 4000 high-quality photographs of the Moon's surface, the spacecraft's success after a long string of failures lifted the morale of space supporters in NASA, JPL, Congress, and the public at large.[58] [II-11] Two subsequent Ranger spacecraft proved equally successful, with the final mission, Ranger 9, carrying the last ten minutes of the spacecraft's journey to the surface on live television—a public-stirring feat the Soviets had not yet accomplished. With the end of the Ranger program, NASA had achieved the best view to date of the

---

54. The history of the Ranger program is exposed in great detail in Hall, *Lunar Impact*.

55. JPL's early Ranger planning efforts can be seen in JPL, "Ranger Project Development Plan, Revision," June 5, 1961.

56. In truth, it turned out, engineers had underestimated the carrying capacities of the launchers, and thus needlessly removed many vital redundant systems. Hall, *Lunar Impact*, pp. 65–67; JPL, "Ranger RA-5 Failure Investigation, Report of JPL Failure Investigation Board," November 13, 1962; NASA, "Final Report of the Ranger Board of Inquiry," November 30, 1962.

57. JPL, "RA-6 Investigation Committee Final Report" Engineering Planning Document No. 205, February 14, 1964; NASA, "Final Report of the Ranger 6 Review Board," March 17, 1964; U.S. Congress, House, Committee on Science and Astronautics, *Investigation of Project Ranger: Hearings before the Subcommittee on NASA Oversight*, 88th Cong., 2nd sess., no. 3 (Washington, DC: Government Printing Office, 1964).

58. For an example of the media's response to Ranger 7's success, see "Impact!" editorial in *The New York Times*, August 2, 1964, p. E1.

Moon and its craters, returning photographs revealing features as small as a meter in size, and had also developed technologies and spacecraft designs to use on future solar system missions.

By the time the first Ranger mission launched, however, NASA's lunar exploration program had begun to change in fundamental ways. When in May 1961 President John F. Kennedy made his landmark announcement of the U.S. intent to send humans to the Moon's surface and return them safely to Earth, the nation readily embraced this chance to make major strides over the Soviets in space.[59] Already underway, the Ranger program piqued the interest of supporters of the manned lunar landing project, dubbed Apollo.[60] Although Ranger originally had been conceived as a program of scientific exploration consisting of five probes, many NASA officials believed the missions could contribute to the understanding of the surface as well as the landing systems that Apollo required. [II-10] Congress willingly appropriated the necessary funds for NASA to fly Rangers 6 through 9 to return high-resolution photographs of the lunar surface.[61] At the request of NASA to find a way to improve the missions' reliability and ensure the success of Ranger's Apollo objectives, JPL removed all scientific experiments from the additional Rangers, leaving only the television cameras.[62]

Despite returning excellent photographs, the Ranger program did not allow scientists to draw many conclusions about the nature or evolution of the Moon because they lacked other vital data. To the chagrin of planetary scientists, NASA had prioritized lunar studies over other solar system targets and then essentially stripped science for its own sake from the lunar exploration program.[63] JPL Lunar Program Director Clifford Cummings made the point while briefing Vice President Lyndon Johnson on October 4, 1961: "Originally our lunar program had been oriented toward scientific and technological objectives. Now…the emphasis has been changed so that support of the manned operations is the primary objective, and space technology and lunar science are secondary."[64]

By November 1961 NASA Administrator Webb had reorganized the agency to create separate offices for space science and manned space flight. Within two years the new directors of the respective offices, Newell and D. Brainerd Holmes, formed a working group of representatives from both offices to recommend a program of space

---

59. John F. Kennedy, "Urgent National Needs," Speech to a Joint Session of Congress, May 25, 1961. See document III-12 in John M. Logsdon, gen. ed., *Exploring the Unknown*, 1:453–54.

60. Oran Nicks to Edgar Cortright, "Lunar Program Support to Manned Lunar Landing," December 6, 1961.

61. NASA Associate Administrator Hugh Dryden testified before the Senate Committee on Science and Astronautics that Apollo's success depended on an improved understanding of the Moon's surface, and requested that Congress extend the Ranger program to meet Apollo's needs. U.S. Congress, Senate, Committee on Science and Astronautics, *NASA Authorization for Fiscal Year 1962: Hearings before the Committee*, 87th Cong., 1st sess., on H.R. 6847 (Washington, DC: Government Printing Office, 1961), p. 56.

62. Oran Nicks to William Pickering, June 9, 1961.

63. Homer Newell realized the disappointment of planetary scientists regarding the change in focus of NASA's lunar exploration program. He expressed to scientists opposed to the burgeoning Apollo project that he expected NASA to reestablish a program that would better serve planetary science's interests in the future. Urey to Newell, October 24, 1962; Homer Newell to Harold Urey, November 15, 1962; Hall, *Lunar Impact*, p. 181.

64. Clifford I. Cummings, "The Lunar Program," *Minutes of Briefing on the Occasion of the Visit of Lyndon B. Johnson, Vice President of the United States of America to the Jet Propulsion Laboratory*, October 4, 1961 (Pasadena, CA: Jet Propulsion Laboratory, October 19, 1961), p. 1.

science data acquisition that would assist planning for Apollo.[65] The Office of Space Science carried out two additional robotic lunar exploration programs for the manned program's benefit.[66] The first of these programs, Surveyor, started as an effort both to softly land spacecraft on the lunar surface and to develop lunar orbiters that would make scientific measurements over several years.[67] Apollo's dominance soon curtailed Surveyor's long-term scientific objectives and modified the program to serve the former's needs. NASA canceled the lunar orbiter portion of the project after grappling with schedule delays and cost escalation in both the Ranger and Surveyor programs as well as problems in the development of Surveyor's launch vehicle, the Atlas-Centaur. JPL managed to launch seven Surveyor spacecraft between 1966 and 1967 with five successful soft landings on the Moon.[68] These probes landed on many types of lunar terrain and returned numerous photographs and data on the composition of the surface.[69]

NASA revived the orbiting spacecraft concept in its second robotic lunar program, Lunar Orbiter. Although designated as an Apollo support project from the start, Lunar Orbiter had the potential to return a significant amount of scientific data. As a result, the project appealed to NASA Headquarters officials favoring manned space flight as well as space science and met the approval of both groups.[70] With JPL already overwhelmed by Ranger and Surveyor, in March 1963 NASA assigned the Langley Research Center in Hampton, Virginia, the task of managing Lunar Orbiter. The objectives of the program were to launch five spacecraft that would return one-meter resolution photographs and other data about the Moon's surface from orbit to facilitate planning Apollo landing sites.[71] From its first launch on August 10, 1966, all five Lunar Orbiter missions successfully fulfilled their objectives. The Lunar Orbiter project provided Apollo with the best lunar surface maps to date and gave flight operators experience tracking spacecraft in orbit around the Moon. After the first three missions satisfied almost all of the Apollo requirements, photographing twenty potential landing sites, scientists were able to use the last two missions to image targets of their choice on the near and far sides of the Moon.

Although NASA's primary intention for Apollo was to demonstrate that the United States could trump the Soviets in engineering a manned lunar landing, many groups supportive of space science pushed the agency to have the Apollo astronauts conduct a program of scientific exploration during their lunar stays. As early as 1962,

---

65. Homer E. Newell and D. Brainerd Holmes, "Establishment of a Joint OSS/OMSF Working Group," October 22, 1962; "Memorandum of Agreement between Office of Manned Space Flight [and] Office of Space Sciences, Scientific Interfaces," no date, signed by E.M. Cortright, July 25, 1963, and J.F. Shea, July 26, 1963.

66. John M. Eggleston to Director, Manned Spacecraft Center, "Utilization of Orbiter and Surveyor in Support of Apollo and Apollo Applications Program Objectives," January 18, 1967.

67. Erasmus Kloman, *Unmanned Space Project Management: Surveyor and Lunar Orbiter* (Washington, DC: NASA SP-4901, 1972), no pagination.

68. Development of the Atlas-Centaur was eventually transferred from the Department of Defense to NASA.

69. NASA, Office of Space Science and Applications, Lunar and Planetary Division, Surveyor Program, *Surveyor Program Results* (Washington, DC: NASA SP-184, 1969).

70. Hall, *Lunar Impact*, p. 209.

71. Bruce Byers, Destination Moon: A History of the Lunar Orbiter Program (Washington, DC: NASA TM-3487, 1977), pp. 96–7.

the Space Science Board polled members of the scientific community for their opinions on possible landing sites for the Apollo missions and experiments the astronauts could conduct.[72] [II-12, II-13] In addition to suggesting what types of space science data robotic spacecraft needed to acquire for Apollo, Newell and Holmes's Joint Working Group also developed Apollo science objectives. Newell solicited the assistance of geologists from the United States Geological Survey to support studies relevant to their expertise.[73] NASA even conducted several conferences to gather scientists interested in the Moon to help prioritize scientific plans and select landing sites.[74] In 1968 NASA established the Lunar Science Institute, a lunar sample and data research facility to be used by university researchers and managed by a university-based consortium; it was located near the Manned Spacecraft Center and Lunar Receiving Laboratory in Houston.[75]

Despite the interest NASA showed, its actual actions regarding science on Apollo were only lukewarm in intensity. On the very first lunar landing mission, NASA officials ended up flying a smaller scientific package than it had intended due to weight requirements of the lunar module and because the larger payload proved cumbersome for suited astronauts to manage.[76] Scientists who had played integral roles in the development of the Apollo science program, including Gene Shoemaker, the geologist who headed the Joint Working Group, denounced NASA for neglecting science in the manned space program and failing to assign any astronauts with scientific backgrounds to Apollo crews as of 1969.[77] Cutbacks in NASA's FY 1971 budget leading to the cancellation of two Apollo missions (in addition to one already canceled earlier) further outraged scientists who counted on the potential scientific returns of those missions. Associate administrator of the Office of Manned Space Flight George Mueller recognized Apollo's weak commitment to science during the first few flights; the last three missions, Apollo 15, 16, and 17, thus carried significantly more scientific experiments aboard the command and service modules as well as lunar surface experiments than their predecessors.[78] Although scientists could not conclusively determine the Moon's origin and evolutionary history

72. Space Science Board memorandum, "Scientific Program for the Apollo Mission," April 20, 1962; "Summary of Responses to SSB Inquiry on Scientific Program for the Apollo Mission," in *Scientists' Testimony on Space Goals, Hearings before the Committee on Aeronautical and Space Sciences*, U.S. Senate, 88th Cong., 1st sess. (Washington, DC: Government Printing Office, June 10–11, 1963).

73. Robert Gilruth to Thomas Nolan, USGS Director, March 29, 1963.

74. William David Compton, *Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions* (Washington, DC: NASA SP-4214, 1989) provides an excellent overview of the role of science and scientists in the Apollo program. *NASA 1965 Summer Conference on Lunar Exploration and Science* (Washington, DC: NASA SP-88, 1965); George E. Mueller to multiple addressees, "Establishment of Apollo Site Selection Board," NASA Management Instruction 1152.20, August 6, 1965; *1967 Summer Study of Lunar Science and Exploration* (Washington, DC: NASA SP-157, 1967), pp. 3–6.

75. Newell, *Beyond the Atmosphere*, pp. 240–42; James Webb to Dr. Frederick Seitz, President, National Academy of Sciences, December 20, 1967. This document appears as III-19 in John M. Logsdon, gen. ed., with Dwayne A. Day and Roger D. Launius, *Exploring the Unknown: Selected Documents in the History of the U.S. Space Program, Volume II: External Relationships* (Washington, DC: NASA SP-4407, 1996), pp. 538–40.

76. See, for example, Edward M. Davin to Manager, Apollo Surface Experiments Program, "Contingency Science Payloads," July 3, 1968, and George M. Low to George W. S. Abbey, "Lunar Mission Planning," September 3, 1968.

77. Homer Newell, author's notebook, December 27, 1969; Newell, *Beyond the Atmosphere*, p. 292. The first scientist-astronaut, geologist Harrison Schmitt, was assigned in 1971 to the crew of Apollo 17, the last Apollo mission.

78. George Mueller to Robert Gilruth, September 3, 1969; Homer Newell, "Conference Report, February 5, 1970, Lunar Science Institute, Houston, Texas, Subject: Critique of Apollo Lunar Missions and the Maximization of Scientific Returns for the Remaining Apollo Flights," February 6, 1970.

from the 380 kilograms of lunar samples and other data returned to Earth, they could confidently posit that the Moon's surface was chemically different than Earth and was in fact as geologically dead as Urey had surmised.[79] [II-24]

Without question, Apollo dominated NASA's solar system exploration effort during the 1960s. The national goal to send humans to the Moon's surface drove the space agency not only to choose lunar over planetary exploration as the primary solar system emphasis during the decade, but also to design its program of lunar scientific exploration to support the human space program. No one at NASA had been directly opposed to science for its own sake; instead, this pressing national objective and relatively limited resources led NASA to exploit the solar system exploration program for reasons other than the pursuit of pure scientific knowledge. In effect, the scientific results of NASA's lunar science program emerged as a byproduct of the Apollo project. In contrast, NASA's efforts to study solar system bodies beyond the Moon, which began very modestly in the early 1960s due to Apollo's prominence, while also designed with an eye towards eventual human interplanetary travel, ended up serving scientific understanding more directly.

To Worlds Beyond Our Moon

Despite initially standing second to lunar exploration, voyaging to worlds beyond the Earth-Moon system was not absent from NASA's early solar system agenda. In December 1959, NASA officials had promised JPL's Pickering that the agency would support the development of probes to visit the planets. Within the next six months, NASA received data from the only successful Pioneer probe, which measured radiation levels and magnetic fields between Earth and Venus, and began planning for missions to Earth's nearest neighbors, Mars and Venus.[80]

Only familiar with solar system bodies via data accumulated from ground-based resources, at the dawn of the space age scientists knew relatively little about the planets. Thus, while from the very start NASA considered spacecraft as elaborate as landers capable of gathering samples and returning them to Earth, the agency recognized that its first missions would have to be devoted to reconnaissance of its targets. The most appropriate spacecraft for its earliest Mars and Venus missions, NASA reasoned, were modest probes that would gather data as they flew by the planets. Orbiting and landing spacecraft, though attractive, seemed far too complex—and risky—while NASA was in its planetary exploration infancy.

JPL designed one spacecraft, called Mariner, with two variations to complete the flybys: Mariner A would perform simple flybys of the planets while Mariner B would release a landing capsule above the planet during its flyby. Initial plans for both models called for launch on the Atlas-Centaur, but problems in the Centaur stage's development forced NASA to reconsider that intention for fear that delays would prevent the

---

79. H. H. Schmitt, Gary Lofgren, G. A. Swann, and Gene Simmons, "The Apollo 11 Samples: Introduction," *Proceedings of the Apollo 11 Lunar Science Conference, Houston, Texas, January 5–8, 1970, Volume I, Mineralogy and Petrology*, ed., A. A. Levinson (New York, NY: Pergamon Press, 1970), pp. 1–54; *Apollo 15 Preliminary Science Report* (Washington, DC: NASA SP-289, 1972).

80. NASA, Office of Program Planning and Evaluation, "The Ten Year Plan of the National Aeronautics and Space Administration," December 16, 1959. After the failure of Pioneer 4 in March 1959, the project's management was transferred from the Department of Defense to NASA.

United States from beating the Soviets to a planetary shot.[81] In August 1961, NASA's Office of Space Flight Development realized it would have to modify its launch plans to achieve a Venus flyby in 1962, and thus canceled Mariner A in favor of a new probe, Mariner R, that would be compatible with the less powerful, but ready for use, Atlas-Agena vehicle. Within a year, JPL planned for Mariner R's scientific capabilities and developed and built the spacecraft, a hybrid of the Mariner A and Ranger designs. Although the first of two planned Venus shots was lost due to failure of the Atlas, Mariner 2 was successfully launched on August 27, 1962. Three and a half months later the probe passed within 16,000 kilometers of Venus, becoming the first spacecraft to flyby another planet and return scientifically valuable data on it and interplanetary space.[82] For 130 days Mariner 2 beamed information to Earth on Venus' climate and clouds and properties of the solar wind.[83] [II-15]

Centaur difficulties eventually led to the cancellation of a 1964 Venus mission and modification of a Mars mission to be launched in the same year. Further delays and a lower than originally predicted lift capacity for the stage forced NASA to scale down and then ultimately abandon Mariner B in favor of a less ambitious design, Mariner C, that lacked a lander and could ride aboard the Atlas-Agena. NASA's first Mariner mission to Mars failed when the upper-stage fairing failed to separate after launch and the solar panels could not deploy. The next spacecraft, Mariner 4, was launched successfully and approached Mars in July 1965. Returning twenty-one television images of the Martian surface as it passed the planet, Mariner 4 showed scientists that Mars' terrain was barren and cratered, like the Moon's, with no apparent canals, water, or signs of life.[84] [II-9]

Not long after JPL began work on the Mariner reconnaissance missions, many scientists started pushing NASA to pursue more ambitious solar system exploration missions. While the early Mariner flyby spacecraft would—and certainly did—provide impressive first close-up views of Earth's nearest planetary neighbors, they were limited in capability and tended to raise more scientific questions than they answered. Solving the mysteries of the planets' origins and evolutionary histories, surface and atmospheric compositions, interior structures, and other properties required probes equipped with larger, more capable instrument suites that could operate around the planets or on their surfaces for extended periods of time. Such desires led scientists and engineers to favor missions relying on increasingly more massive spacecraft, more powerful launch vehicles, and of course, larger budgets. The costs and technical complexity associated with ambitious missions often ran these projects or the entire solar system exploration program into trouble.

As early as 1961, JPL had studied possibilities for Mars and Venus exploration to follow the never-materialized Mariner B. JPL's preferred concept, called Voyager, was an ambitious program that would consist of orbiting as well as landing spacecraft that would carry more scientific instruments, collect and return more data, and operate for much

81. Ezell and Ezell, *On Mars*, p. 35.

82. Although the USSR's Venera 1, launched February 12, 1961, became the first spacecraft to flyby Venus in May 1961, contact with the spacecraft was lost a week after launch. Mariner 2 thus became the first spacecraft to fly by and return data on the planet.

83. NASA, *Mariner-Venus 1962: Final Project Report* (Washington, DC: NASA SP-59, 1965), pp. 12–15, 87–120. This early planetary mission did not carry a camera.

84. NASA, *Mariner-Mars 1964: Final Project Report* (Washington, DC: NASA SP-139, 1967).

longer than the Mariner probes.[85] Among the instruments scientists hoped to send to Mars were elaborate experiments to detect the presence of life on the planet that had long been suspected to harbor living creatures.[86] [II-16, II-17] Initially intending to send an orbiter and lander pair to both Venus and Mars, NASA ended up approving in 1964 four Mars-only Voyager flights—two in 1971 and two in 1973—at a cost of approximately $1.25 billion. [II-18] Deciding that Mars was its primary target and Voyager was the spacecraft with which it wanted to achieve its scientific goals, the agency eliminated Venus from Voyager plans and canceled two Mariner missions to Mars for 1966 and 1969 to assure the availability of funds for Voyager.[87]

Voyager's ambitiousness, coupled with political and economic circumstances, brought about difficulties in mission planning and ultimately led to the program's demise. Early on, some scientists and engineers questioned the wisdom of undertaking such a costly, sophisticated project; money aside, they wondered whether NASA had enough data on Mars from its first Mariner mission to the planet to design a suitable lander and to select an appropriate landing site by 1971. Moreover, the Voyager Lander was large and engineers struggled to develop a means of sterilizing the spacecraft for landing on Mars without destroying the functionality of its systems.[88] [II-14] Delays in the planned launch date occurred when NASA discontinued Saturn 1B—the vehicle initially intended to launch the Voyager spacecraft—and announced that the missions would fly on Saturn V, which would not be ready until at least 1967.[89] These delays pushed back the missions' launch dates; NASA's cost projection of the entire Voyager program grew to $2.2 billion through 1977.[90] At the same time, national priorities such as the conflict in Vietnam and President Johnson's Great Society programs were competing for funds with Apollo, and as a result, NASA began in 1965 to transfer funds from space science projects, including Voyager, to support its highest-priority manned lunar project.

By the end of 1965, NASA officials decided to cancel the 1971 Voyager mission after receiving only $10 million in the FY 1967 budget to begin flight hardware development. When the 1973 mission received no appropriations from Congress in FY 1968 and the White House made no attempt to restore NASA's request for Voyager, NASA did not attempt to reinstate the project. In lieu of this project, NASA flew Mariner spacecraft less

---

85. Bruce Murray, California Institute of Technology Associate Professor of Planetary Sciences, to Lee DuBridge, President, California Institute of Technology, February 23, 1965; California Institute of Technology, "Suggestions for Martian Exploration Following Mariner 4," February 23, 1965. Voyager Mars should not be confused with the late 1970s' Voyager mission to the outer planets.

86. Since its establishment in 1959, NASA's ad hoc Bioscience Advisory Committee had urged NASA to search for life on Mars. The Space Science Board had also encouraged biological studies on Mars. See Space Science Board, *Biology and the Exploration of Mars: Summary and Conclusion of a Study Supported by the NASA* (Washington, DC: National Academy of Sciences, 1965); Space Science Board, *Biology and the Exploration of Mars: Report of a Study Held Under the Auspices of the SSB, National Academy of Sciences-National Research Council, 1964–1965* (Washington, DC: National Academy of Sciences, 1966).

87. Robert Seamans to Donald Hornig, December 14, 1964, and James Spriggs to Homer Newell, "Voyager 1969," December 7, 1964.

88. Since NASA's inception, scientists were concerned that unsterilized spacecraft sent to other planets could carry terrestrial microbes. Some claimed that such "biological contamination" of other planets would be unethical. Many feared that sending unsterilized spacecraft to the planets would compromise scientists' ability to identify a microbe on another planet as indigenous to that planet. Both concerns led NASA to take measures in preparing spacecraft to ensure "planetary protection." Incidentally, the Soviet Union did not completely sterilize its early Mars spacecraft. Ezell and Ezell, *On Mars*, pp. 55–6, 104.

89. Ezell and Ezell, *On Mars*, p. 105.

90. *Ibid*., p. 113.

capable than Voyager but more sophisticated than the earlier Mariners to Venus in 1967 and to Mars twice in 1969.

Planetary Exploration After the Height of Apollo

The combination of Voyager's cancellation, disagreement among scientists on planetary science objectives, and the start in 1967 of a downward trend in space science funding—and for all space program budgets, as the Johnson Administration reduced NASA's budget after Apollo's development was nearly complete—led NASA Administrator Webb that fall to temporarily halt work on new planetary missions to force the agency to reassess its plans to explore the solar system. Managers in the Office of Space Science and Applications developed several options on the course NASA's planetary exploration program could take.[91] They decided that while NASA had no commitments to fly any missions after the 1969 Mars Mariners, the agency should continue space science technology development and have ready a "wish list" of mission concepts to pursue should more money become available.[92] [II-21]

Scientists had mixed ideas regarding the strategy NASA should take for planetary exploration. The Space Science Board, for example, advised NASA to begin a program of "Planetary Explorers"—small, low-cost planetary missions, akin to the existing small Explorer missions for astronomy and space physics, to ensure frequent launches of solar system missions.[93] In contrast, the Lunar and Planetary Missions Board, a group of advisors from academia, research institutes, and aerospace corporations established by NASA in 1967 to critique the scientific merit of the agency's solar system exploration missions, suggested a more ambitious planetary program, which NASA rejected due to its high estimated cost.[94] When Webb appeared before the Senate Committee on Aeronautical and Space Sciences in November 1967, he proposed a revised planetary program that included five Mariner missions between 1971 and 1976 and a less ambitious Voyager-type, orbiter-probe mission to Mars in 1973, possibly to be followed in 1975 with a soft-landing mission.[95] [II-22] The Space Science Board believed the scheme to be overly ambitious while the Lunar and Planetary Missions Board thought NASA was not asking for enough. Webb, however, believed his own plan represented a balance between the desires of both groups, including enough activity to keep the planetary program agenda full while not requiring unrealistic amounts of money. The soundness of Webb's decision became evident when the

91. The Office of Space Sciences was named the Office of Space Sciences and Applications (see Chapter 1, page 12) during Webb's reorganization of NASA Headquarters in 1967.

92. Ezell and Ezell, *On Mars*, p. 134; James Martin to Charles Donlan, "OSSA Proposed Planetary Programs," October 5, 1967; "Planetary Program Extension, FY 1968–1969: Program Issues and Options," October 9, 1967.

93. NASA's Goddard Space Flight Center developed the Planetary Explorer concept when it conducted its own study in 1968 to investigate the capabilities of small planetary orbiters using Explorer spacecraft. The 1978 Pioneer Venus mission became NASA's first and only such Planetary Explorer. For the Space Science Board's recommendation on Planetary Explorers, see Space Science Board, *Planetary Exploration: 1968–1975* (Washington, DC: National Academy of Sciences, 1968).

94. The Lunar and Planetary Missions Board's efforts eventually led to the successful completion of planetary missions throughout the 1970s. See Ezell and Ezell, *On Mars*, pp. 144–48 and Barry Rutizer, "The Lunar and Planetary Missions Board," HHN-138, August 30, 1976, at the NASA History Office.

95. U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, *NASA's Proposed Operating Plan for Fiscal Year 1968, Hearing*, 90th Congress, 1st session (Washington, DC: Government Printing Office, November 8, 1967), p. 16.

plan met the approval of Congress and, most importantly, when President Johnson noted in his January 1968 budget address to Congress: "We will not abandon the field of planetary exploration."[96]

The Johnson Administration remained true to its pledge, and NASA's proposed missions received the funding and new starts they needed. [II-23] After the success of the two Mariner probes to Mars in 1969, NASA attempted in 1971 to send two more Mariners to the Red Planet, not to fly past but to achieve orbit around the planet in order to return data at close range and over several weeks. Based on the early Mariner spacecraft design and ground equipment but larger in mass and more complex, JPL's new Mariner probes would orbit the planet for at least 90 days apiece. Planetary scientists hoped that long-term study of Mars would reveal information about the planet's weather patterns, polar cap phases, its potential of ever having sustained life, and possible landing sites for the future NASA Mars Lander. After Mariner 8 ended in a launch failure, Mariner 9 successfully left Earth on May 30, 1971, and became the first probe ever to enter orbit around another planet. Scientists feared the spacecraft would return little data when it arrived in the middle of a dust storm that swept across the entire planet, but within a couple of months the dust settled to reveal the planet's colossal canyons and mountains. Contrary to Mariner 4's bleak portrayal of Mars, Mariner 9 returned images of ancient lava flows and waterways, suggesting that Mars had had a very active geological past.[97]

Two years later, NASA launched its final Mariner mission. A flyby of Venus and Mercury, Mariner 10 became the first spacecraft to visit more than one planet. It remains the only probe to have visited the closest planet to our Sun. The mission returned photographs of almost half of Mercury's surface and revealed that the planet once had an intrinsic magnetic field.[98]

Perhaps most significantly for NASA's planetary exploration program in the era of Apollo flights, the Johnson Administration and Congress also allocated ample funding for the agency to land spacecraft on the surface of Mars to examine the planet's surface environment and search for the possibility of life. As originally proposed by Webb, during the mid-1970s the agency would deliver both orbiting and landing spacecraft to Mars—all of which would be based on a less ambitious Voyager design. During the fall of 1968, NASA officials met with representatives from JPL and Langley, the two Centers that would manage the mission, and potential contractors to explore alternatives for orbiters, landers, entry modes, and launch vehicles for the missions.[99] Although NASA managers and the Langley team concluded that flying two orbiter and soft lander pairs would be the most

96. "Planetary Exploration Program: Collection of Comments, Policy Statements, etc. (excerpts from NASA Press Conference on FY 69 Budget, January, 29, 1968)," no date; Ezell and Ezell, *On Mars*, p. 135.

97. For Mariner 9's scientific achievements, see Jet Propulsion Laboratory, "Mariner Mars 1971 Final Project Report, Volume V: Science Experiment Reports" (Pasadena, CA: JPL Technical Report 32–1550, August 20, 1973) and William K. Hartmann and Odell Raper, *The New Mars: The Discoveries of Mariner 9* (Washington, DC: NASA SP-337, 1974).

98. For more on the achievements of Mariner 10, see Schorn, *Planetary Astronomy*, pp. 257–58, 260–61.

99. Though JPL had vied for complete control of the mission, NASA preferred Langley's proposed management scheme and awarded the latter Center primacy over the mission's development. "NASA-LRC/JPL Management Agreement for Advanced Planetary Mission Technology Mars Lander-Mission Study," August 1968; Watson, "Viking Project Phase B Report," M63–110–0 [Circa Nov 1968]; William Pickering to Charles Donlan, April 17, 1968; Eugene Draley, "Langley Research Center Management Proposal for 1973 Mars Mission," April 18, 1968; Ezell and Ezell, *On Mars*, pp. 148–49.

expensive and technically complex choice, space sciences head John Naugle presented this scientifically optimal option under the name Viking to NASA Acting Administrator Thomas Paine in November 1968.[100] The following month, Naugle and Paine—a planetary exploration advocate who was concerned about catching up with the 1967 Soviet landing of Venera 4 on Venus—selected a Viking mission scheme to send two orbiter-lander pairs to Mars for an estimated $415 million. Each mission would include a soft lander with a surface lifetime goal of 90 days; the lander would be released from a Mariner 1971-class orbiter that would provide wide-area surveillance and a communications link for the lander. A Titan III-Centaur combination would boost each of the two orbiter-lander pairs to Mars in 1973.

Work began on the project immediately, with JPL designing and building the orbiter, Langley supervising lander development and system integration, Martin Marietta constructing the lander, and Lewis Research Center in Cleveland, Ohio, overseeing launch vehicle development.[101] Within the early months of development, it became clear that the Viking project would surpass its originally estimated cost figure. While the orbiter borrowed heavily from Mariner technology, JPL engineers nonetheless had to make significant changes to the design to enlarge the orbiter and its systems so they could power the lander before its release. The lander's sophisticated computer and biology and gas chromatograph-mass spectrometer instruments further contributed to the quickly rising costs.[102] As Viking's price tag escalated, NASA's budget continued to shrink. After reviewing projections for NASA's FY 1971 budget, NASA opted in 1970 to postpone the Viking missions' launches until 1975, which increased costs as well.[103] By the time the spacecraft were launched in 1975, NASA had spent over $1 billion on what had been intended to be a more modest alternative to the overgrown Voyager concept.

The Viking 1 Orbiter-Lander pair was launched from Cape Canaveral aboard a Titan III-Centaur launch vehicle on August 20, 1975, followed less than three weeks later by the identical Viking 2. After arriving in orbit around Mars, the Viking 1 Orbiter began its first task: photographing the surface regions that the Landing Site Working Group had selected for the Viking Landers to visit based on Mariner 9 data.[104] Revealing surface features in unprecedented detail, the orbiter showed the early landing site choices for both landers to be hazards, covered with craters, depressions, grooves, and ridges. This discovery dismayed the Viking team, for they had hoped to make the United States' first landing on Mars on July 4, 1976, the bicentennial of the Declaration of Independence. Despite the intense desire to meet this target date, they decided to delay the landings while the landing site staff analyzed the orbiter data to make new

---

100. NASA had initially referred to the mission concept as Titan Mars 1973 because the spacecraft would launch on a Titan III-class booster. A. Thomas Young, "Titan Mars '73 Mission Mode Meetings Summary," November 14, 1968.

101. Viking was the first NASA planetary project in which multiple NASA Centers and contractors participated in the design, development, and operations phases. Ezell and Ezell, On Mars, p. 153; James Martin, "Procurement Planning, Mars '73 Mission," February 13, 1968; James Martin, "Mars '73 Statement of Work," June 13, 1968, with enclosures; Langley Research Center, Viking Project Office, "Viking Project Mission Definition No. 2," M73–112–0, August 1969.

102. Viking Project Office, "Viking Lander Science Instrument Teams Report," M73–112–0, August 1969.

103. John Naugle to Edgar Cortright, "The Cost of the Viking Project," August 26, 1969; John Naugle, memo for record, "Decision to Reschedule Viking to 1975," January 4, 1970.

104. Gerald Soffen to James Martin, "Landing Site Recommendation," April 3, 1973.

selections. The Viking team realized the prudence of their new choices—and of postponing the mission—when the two landers touched down successfully on the planet's northern hemisphere: Viking 1 at Chryse Planitia on July 20, 1976, and Viking 2 at Utopia Planitia on September 3, 1976.

Most planetary scientists agreed that Viking's returns made up for its high price tag. For six years, the thirty-four instruments of the orbiters and landers worked together to paint the most detailed picture of Mars that planetary scientists had to date.[105] The probes showed the Martian surface to be a cold, dry desert whose plains were strewn with rocks and sand dunes. The landers' color cameras—the first ever sent on a robotic spacecraft—showed Mars' iron-rich terrain to be a rusty red and the sky reddish-yellow from its high dust content. Vast canyons, tall mountains, and networks of tributaries were telltale signs that tectonic and volcanic activity and water and wind erosion had altered the surface over the planet's history.[106] The atmosphere, much less dense now than in Mars' past, contained trace amounts of water; scientists speculated that the planet must store more water below the surface or at the poles.[107] [II-26]

Scientists and the public did experience one major disappointment regarding the Viking mission: its failure to detect any unambiguous signs of life on the Red Planet. For a century, science fiction authors had created in the worldwide public's mind an image of Mars as a life-friendly planet. Scientists who had studied Mars also suspected that the planet once, and possibly still, harbored at least microbial life forms. But Viking turned up no signs of life: the landers' cameras did not photograph any living creatures and their highly sensitive life detection experiments found no evidence of microbial life in the Martian dirt.[108] Though some scientists argued that this negative result was just as informative as a positive one, the failure of these experiments—arguably the mission's most intriguing—to discover life dashed the hopes of both scientists and the public. With Viking's depiction of Mars as a cold and lifeless planet, NASA reduced its support for further robotic exploration of the Red Planet and redirected its focus to other areas of the solar system.[109]

Although NASA's funding was shrinking, the agency succeeded in gaining White House and congressional approval for yet an additional pair of major missions in the late 1960s. While Mars had been the primary target of planetary scientists and the agency because of its enigmatic history and accessibility using current launch capability, the outer solar system still beckoned. Both the Lunar and Planetary Missions Board and the Space Science Board maintained that Jupiter and the planets beyond were intriguing targets about which humanity knew very little, and that NASA ought to consider sending low-cost

105. The Viking 2 Orbiter ceased functioning in 1978, while both Viking 2 Lander and Viking 1 Orbiter continued operating until 1980. The Viking 1 Lander stopped working in 1982.

106. Viking Lander Imaging Team, *The Martian Landscape* (Washington, DC: NASA SP-425, 1978).

107. For a comprehensive overview of Viking's achievements during its first year of operation, see Gerald A. Soffen et al., "Scientific Results of the Viking Project," *Journal of Geophysical Research* 82 (September 30, 1977): 3959–70. This article introduces a full issue of *Journal of Geophysical Research* devoted to Viking's returns. See also Gerald A. Soffen and Conway W. Snyder, "The First Viking Mission to Mars," *Science* 193 (August 27, 1976): 759–65.

108. For results of Viking's search for life on Mars, see, for example, Norman H. Horowitz, "The Search for Life on Mars," *Scientific American* 237 (November 1977): 57–8 and "Life on Mars?…" *New York Times*, September 20, 1976.

109. Opposition to a robotic Mars sample return mission, which had been discussed at NASA throughout Viking's development, can be seen, for example, in Daniel Herman, Advanced Programs and Technology Manager, to Lunar and Planetary Programs Director, June 14, 1977.

spacecraft to explore them. The Space Science Board specifically recommended that such an objective could be achieved by sending two Pioneer-class probes to Jupiter at opportunities in 1972 and 1973.[110] In February 1969, NASA Headquarters embraced the Space Science Board's advice and approved a pair of missions to provide the first close-up look at the largest planet in the solar system. Congress and the White House approved the plan later that year.

As originally planned, the new Pioneer project would explore the interplanetary medium beyond Mars' orbit, investigate the asteroid belt, and explore the planet Jupiter and its environment.[111] Managed by Ames Research Center at Moffett Field, California, the Pioneer spacecraft were identical small, lightweight (258 kilograms) probes based on the modules used for interplanetary Pioneers 6, 7, 8, and 9.[112] Because they would have to endure long distances and traverse the asteroid belt, whose hazards were not fully understood, the spacecraft were very simple and boasted several redundant key subsystems. Two spacecraft were built due to the very fact that engineers feared that one of the probes would fail before reaching Jupiter.

In March 1972 and April 1973, Pioneers 10 and 11 were successfully launched on Atlas-Centaur vehicles to begin what would become the most distant voyages human-made probes had made to date. Pioneer 10 was a pioneer in the true sense of the word, for its experiences would tell NASA how successfully spacecraft could pass through the asteroid belt, endure Jupiter's intense radiation, operate using not solar power but onboard nuclear power sources, and communicate across extreme distances from Earth. This spacecraft and its twin proved their abilities to achieve all of the above feats in addition to collecting and returning phenomenal science during their travels to and flybys of Jupiter. Using a combined total of 23 instruments, the two spacecraft mapped the magnetic field and distribution of dust particles in interplanetary space while exploring how the interplanetary magnetic field interacted with the solar wind and cosmic rays. Travelling through the asteroid belt permitted the spacecraft to investigate properties of the objects scientists and engineers had feared could destroy their efforts to reach the outer solar system. In Jupiter's environs, the probes gathered data on the magnetic and gravitational fields, temperatures, and atmospheric properties of the planet and its four inner moons. After Pioneer 10 made the first successful Jupiter flyby, NASA made the decision as Pioneer 11 was en route that the latter spacecraft would continue on to explore Saturn after providing additional information on Jupiter. At Saturn the probe made measurements of the planet's physical and chemical properties while also discovering a new ring and new moon around the planet.

After the completion of their mission objectives at Jupiter and Saturn, the probes began their journeys in opposite directions to find the heliopause—the "envelope" around the solar system beyond which the Sun does not influence interplanetary space—

---

110. Space Science Board, *Planetary Exploration*, 1968–1975 (Washington, DC: National Academy of Sciences, 1968).

111. For a comprehensive overview of the history and achievements of Pioneers 10 and 11, see Richard O. Fimmel, James Van Allen, and Eric Burgess, *Pioneer: First to Jupiter, Saturn, and Beyond* (Washington, DC: NASA SP-446, 1980).

112. Ames Research Center had developed spin-stabilized probes for NASA's revived Pioneer program. NASA launched Pioneers 6, 7, 8, and 9 between 1965 and 1968 to investigate properties of the interplanetary medium and the effects of the Sun on the inner planets.

and eventually to leave the solar system. Though they no longer transmit data to Earth since NASA terminated the missions a few years ago, both carry gold-anodized aluminum plates showing their origins in the solar system as emissaries of humanity. Journalist Eric Burgess and Cornell planetary scientist Carl Sagan encouraged NASA to add these plaques to the probes to convey to an intelligent civilization, which might find and decipher the plaques millions of years from now, the desire of another species to leave its own planet and explore the universe.[113]

Planetary Exploration in the 1970s

NASA had managed in the late 1960s to gain authorization and funding from Congress to develop nine spacecraft to explore the solar system. But by the middle of the new decade, the planetary program was experiencing tremendous difficulty securing new starts for missions. NASA's total budget had been declining since Apollo's development funding peaked in 1966; by 1969 the space science budget reached a low that it had not seen since 1961. With the Apollo program to end in the early 1970s, NASA sought to start on a new human space flight program: a reusable human launch vehicle which came to be known as the Space Shuttle.[114] As Apollo had before it, the new human space flight project consumed a large proportion of the dwindling NASA budget. At the same time, Viking's complexity and price tag were escalating and Mariner 10 and Pioneers 10 and 11 were in development. In effect, the space agency could afford to initiate few planetary exploration missions in the 1970s. Thus, before the three projects NASA and Congress chose to begin supporting in the 1970s, which sought to help refine planetary scientists' understanding of the solar system, they endured debates and several modifications to meet the resource constraints of the times.

Throughout NASA's first several years, scientists and engineers only explored the solar system as far as the orbit of Mars. Assuming that they could only reach the outer planets by means of reaction propulsion, they could not devise propulsion systems powerful enough to achieve such distances. In 1961, Michael Minovitch, a graduate student from the University of California, Los Angeles, working at the Jet Propulsion Laboratory, discovered a method of propelling spacecraft through the solar system that would not rely exclusively on fuel but would leverage the gravitational pull of planets as they approached these bodies.[115] Minovitch postulated that gravity-propelled interplanetary space travel would limit the fuel required on spacecraft, thus making them easier to launch, while often shortening the time otherwise required for them to reach their destinations. [II-20] California Institute of Technology graduate student Gary Flandro attempted later that decade to apply this principle to develop

---

113. Fimmel, Van Allen, and Burgess, *Pioneer: First to Jupiter, Saturn, and Beyond*, p. 248; Carl Sagan, Linda Salzman Sagan, and Frank Drake, "A Message from Earth," *Science* 175 (February 25, 1972): 881–84; NASA News Release 72–32, February 25, 1972.

114. More details on the development of the Space Shuttle can be found in chapter two of John M. Logsdon, gen. ed., with Ray A. Williamson, Roger D. Launius, Russell J. Acker, Stephen J. Garber, and Jonathan L. Friedman, *Exploring the Unknown: Selected Documents in the History of the U.S. Space Program, Volume IV: Accessing Space* (Washington, DC: NASA SP-4407, 1999), pp. 161–404.

115. M. A. Minovitch, "A Method for Determining Interplanetary Free-Fall Reconnaissance Trajectories," JPL Technical Memo 312–130, August 23, 1961, pp. 38–44.

trajectories to reach planets beyond Mars.[116] [II-19] Starting in the late 1970s the outer planets would be aligned such that a probe launched to Jupiter could leverage that planet's gravity to boost it to Saturn, where it would receive another "gravity assist" to launch it to Uranus, which would slingshot it to Neptune.[117] A spacecraft built by that time could take a "grand tour" of all of the outer planets except Pluto.

In 1969, the same year that Congress approved Pioneers 10 and 11, NASA heeded these efforts and began designing a mission concept, called the Grand Tour, around this rare opportunity. Much more ambitious than the Pioneer mission, the Grand Tour called for dual spacecraft launches to Jupiter, Saturn, and Pluto in 1976 and 1977 and dual launches to Jupiter, Uranus, and Neptune in 1979, with an estimated total cost of $750 million. Even before receiving a new start, NASA selected about a dozen teams of scientists to develop the mission's scientific objectives, while JPL and industrial contractors proceeded to draw up designs for the advanced spacecraft that would carry the instruments.[118] Budget constraints, however, meant that the space agency could only allocate $10 million of the $30 million the Grand Tour's developers requested to complete the design phase of the mission in FY 1972.[119]

NASA significantly descoped the mission and received the approval of Congress and President Nixon for a new start in FY 1973. The agency revised its plans to take advantage of the unique alignment of the outer planets by dropping Uranus, Neptune, and Pluto from its targets and redesigning the mission to use the proven Mariner-class spacecraft to improve reliability and to lower the costs of development. The new $250 million concept began with the name Mariner Jupiter-Saturn, but in 1977 NASA renamed the project Voyager.[120] In 1972 NASA selected nine instruments from more than 30 proposed to satisfy Voyager's mission objectives to study Jupiter and Saturn, those planets' satellites, the interplanetary medium, and possibly Uranus. Two identical spacecraft weighing 815 kilograms and equipped with numerous redundant systems were built for the mission. Following the example of Pioneers 10 and 11, each also carried a special memento: a gold-plated copper phonograph record containing images, sounds, and spoken greetings representative of the diversity of life and cultures on Earth.[121]

The Voyager spacecraft were launched on August 20 and September 5, 1977, from Cape Canaveral on Titan III-E/Centaur vehicles.[122] Arriving at Jupiter in 1979, the two spacecraft sent back the best resolution images to date of the planet's enormous, turbu-

116. G. A. Flandro, "Fast Reconnaissance Missions to the Outer Solar System Utilizing Energy Derived from the Gravitational Field of Jupiter," *Acta Astronautica* 12 (July/August 1966): 329–37.

117. R. D. Bourke and G. A. Flandro to T. A. Barber and F. N. Haurlan, October 10, 1966. The outer planets achieve this alignment once every 176 years.

118. NASA, "Invitation for Participation in the Mission Development for Grand Tour Missions to the Outer Solar System," October 1970; David Morrison and Jane Samz, *Voyage to Jupiter* (Washington, DC: NASA SP-439, 1980), p. 24.

119. George M. Low, Personal Notes #40, January 22, 1971.

120. Grand Tour enthusiasts also had proposed a Mariner Jupiter-Uranus mission to be launched in 1979 for $400 million, but the costs of Voyager and the possibility of sending the spacecraft to Uranus after the successful completion of the primary mission precluded NASA from starting on such a mission.

121. The complete story of the Voyager records' conception and compilation can be found in Carl Sagan, Frank Drake, Ann Druyan, Timothy Ferris, Jon Lomberg, and Linda Salzman Sagan, *Murmurs of Earth: The Voyager Interstellar Record* (New York, NY: Ballantine Books, 1978).

122. Voyager 2 was the first to launch, but Voyager 1 was set on a shorter, faster trajectory that enabled it to reach Jupiter first.

lent atmospheric storm—seen from Earth as the Great Red Spot—and the vastly diverse terrains of the four inner moons. They also detected a faint ring of particles encircling the planet as well as a plasma torus produced by the moon Io. Voyager 1 flew by Saturn and its largest moon, Titan, in 1980 before proceeding on a trajectory that took it out of the solar system, while Voyager 2 reached Saturn the following year to yield new information on the planet's atmospheric dynamics, ring structure, and satellites.[123] With the original mission objectives completed and the spacecraft still healthy, Voyager's managers requested approval from NASA Headquarters to send Voyager 2 onward to Uranus.[124] [II-27, II-28, II-29] After a successful flyby of that planet in 1986, the spacecraft traveled on for a 1989 rendezvous with Neptune, making the only approach to these two planets of any spacecraft to the present.

NASA's second planetary new start of the 1970s took probes back to Venus. In the late 1960s, American planetary scientists wishing to catch up with the Soviets' success in releasing a probe into Venus's atmosphere began planning for their own Venus Orbiter and probe mission.[125] Such a mission would allow them to study the planet's surface using radar from on orbit and probing the atmosphere with *in situ* measurements. Scientists and engineers at NASA's Goddard Space Flight Center studied the feasibility of using the Planetary Explorer concept to develop a low-cost Venus Orbiter, and also examined a number of probe options.[126] Members of both the Space Science Board and the Lunar and Planetary Missions Board agreed that Venus was still an important scientific target and endorsed NASA's use of low-cost orbiters and probes to conduct in-depth investigation of the planet.[127] Although the scientists originally envisioned sending several orbiters and probes to the planet throughout the decade beginning in 1973, a $200 million mission cost cap forced the team to settle on a single orbiter and multiprobe—comprised of a large probe and three smaller ones—in the late 1970s. This mission took the name Pioneer Venus, and became the only mission NASA ever designed and executed around the Planetary Explorer concept. In 1974 Congress authorized this downscaled version of a Venus mission for a new start in the following fiscal year, and NASA awarded the Hughes Aircraft Company a contract to build the orbiter and probe.

The orbiter and multiprobe were launched on separate Atlas-Centaur vehicles in 1978. On December 4 of that year the orbiter entered orbit around Venus. The constituent probes of the multiprobe separated to make individual, hour-long descents through the planet's atmosphere five days later. Arriving in different zones around the planet, all of the probes successfully returned *in situ* data on the atmosphere's composition, structure, and temperature before impacting the surface.[128] The orbiter also

123. For the results of Voyager's flyby of Saturn, see David Morrison, *Voyages to Saturn* (Washington, DC: NASA SP-451, 1982).

124. Raymond L. Heacock to Frank Carr, October 21, 1980; Raymond L. Heacock to Frank Carr, November 24, 1980; Frank Carr to Raymond L. Heacock, December 12, 1980.

125. The story of Pioneer Venus's development and achievements can be found in Richard O. Fimmel, Lawrence Colin, and Eric Burgess, *Pioneer Venus* (Washington, DC: NASA SP-461, 1983).

126. R. M. Goody, D. M. Hunten, V. Suomi, and N. W. Spencer, *A Venus Multiple-Entry-Probe Direct-Impact Mission* (Greenbelt, MD: NASA Goddard Space Flight Center, 1969).

127. Space Science Board, *Venus: A Strategy for Exploration* (Washington, DC: National Academy of Sciences, 1970).

128. Although the probes were not designed to survive impact, one of the probes survived and continued to transmit data for over an hour.

gathered data on the atmosphere, but more importantly became the first spacecraft to “see” through the thick atmosphere using radar and to map the entire Venusian surface.

By the mid-1970s, NASA officials and planetary scientists were expressing their worries about the reduced frequency in new starts for solar system exploration programs. Referring to the decline in funding for lunar and planetary exploration since 1974, NASA Associate Administrator for Space Science Noel Hinners told a Senate committee during a NASA FY 1977 budget hearing that at the current rate of budget decline, the solar system exploration program was on a “going-out-of-business” trend.[129] Others voiced their concerns to top national science officials that the lack of new starts in favor of other NASA priorities would destroy the program of solar system exploration that NASA had worked so hard to build up over nearly two decades.[130] [II-25] Only after scientists and NASA representatives offered extensive testimony to Congress, and Congress took several votes, did the FY 1978 budget include a new start for a planetary program—the last the space agency would see until 1984.

During the course of Voyager’s development, NASA had begun looking ahead to the possibility of sending to Jupiter a long-lived orbiter with a probe that could be released into the planet’s atmosphere. Originally called the Jupiter Orbiter Probe, the project’s name was changed to Galileo shortly after receiving its FY 1978 new start in honor of the discoverer of the planet’s four largest moons. Slated to cost no more than $750 million (FY 00 dollars), the spacecraft was scheduled to launch in 1982 for a 1984 arrival at Jupiter. During the remainder of the decade, those involved in the program at NASA began orbiter development based on a Voyager-type design and a probe based on Pioneer Venus, selected the scientific experiments for the mission, and reached an agreement with Germany for that nation to develop the engine for the probe.

As the next section shows, Galileo nearly faced cancellation several times in the late 1970s and early 1980s due to competition with the development of the Space Shuttle and other space science projects for scarce budget dollars. Once the decision was made to preserve the project, problems with the development of the Inertial Upper Stage—the mechanism scheduled to deploy Galileo from the Shuttle, which was NASA’s new vehicle of choice for launching all types of probes—pushed the Galileo craft to a 1986 launch date. The unexpected *Challenger* disaster that occurred early that year grounded Galileo for another three years, and only after the Shuttle program resumed was the spacecraft finally launched in 1989. By the time of its launch, the repeated delays had boosted the mission’s price to well over $1.4 billion (FY 00 dollars). A long wait on the ground also unfortunately led to the wearing away of lubricant on the orbiter’s high-gain antenna, which was supposed to permit the return of science at high data rates. As a result, the antenna was unable to open completely once in space, and so mission operators had to rely on the spacecraft’s smaller antenna, which had slower data return rates. [II-37] The Galileo Orbiter and probe still managed to return a wealth of data, beginning in 1995, on the nature of Jupiter’s atmosphere and magnetosphere as well as its four inner moons. Imaging with a solid-

---

129. U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, *NASA Authorization for FY 1977, Hearings, Part 2* (Washington, DC: Government Printing Office, February 1976), p. 1138.

130. G. J. Wasserburg to H. Guyford Stever, June 8, 1976.

state detector represented a marked improvement in sensitivity and resolution over Voyager's vidicon television camera system, and enabled Galileo scientists to make stunning revelations about the features on the planet's moons.[131]

Keeping the Planetary Program Alive in the 1980s

Viking, Voyager, Pioneers 10 and 11, and Pioneer Venus were still operating at the end of the 1970s, but solar system enthusiasts were only partly consoled by their scientific returns. Looming large in their minds was concern for the planetary program's welfare beyond those projects.[132] NASA's budgets were tight, its program objectives were numerous, and the agency had only one planetary mission, Galileo, in the works. In 1979 the financial crunch induced NASA to abandon its plan to send a spacecraft to rendezvous and "fly in formation" with Halley's Comet, due to pass near the Sun during 1985 and 1986.[133] While the Soviet Union, European Space Agency, and Japan would all greet the comet that visited the inner solar system once every 76 years, lack of support for planetary exploration at the end of the 1970s meant the United States—then the world's major space player—would miss out on the opportunity.[134]

These tough times led to the appearance of two new organizations within the planetary science community. Having returned to NASA as Chief Scientist in the late 1970s, John Naugle recognized that NASA had abandoned its habit of developing long-term strategies for solar system exploration, and that the lack of an integrated strategy made missions vulnerable to descoping or outright cancellation when other projects took priority.[135] In response, Naugle formed the Solar System Exploration Committee (SSEC), an *ad hoc* committee of the NASA Advisory Council, to "review the goals of solar system exploration; identify the essential attributes of a viable program in planetary sciences; and define new ways to reduce costs.[136] In addition, JPL's Bruce Murray, Louis Friedman (formerly of JPL), and Carl Sagan founded The Planetary Society in Pasadena, California, to gain grassroots support for the endangered planetary program. Eventually attaining a membership of more than 100,000, The Planetary Society has become the most visible pro-space group in the world.[137] [II-30]

---

131. Galileo has returned high-resolution images showing the diversity and enigma of Jupiter's four largest moons: cratered Callisto, mottled Ganymede, volcano-pocked Io, and icy Europa.

132. For an excellent review of the difficulties NASA's planetary exploration program faced in the early 1980s, see John M. Logsdon, *The Survival Crisis of the U.S. Solar System Exploration Program* (unpublished), June 1989. This document was prepared for the NASA History Office.

133. For discussions of the United States' failure to conduct a Halley's Comet mission, see John M. Logsdon, "Missing the Comet: Why No U.S. Mission to Halley," *ISIS* 80 (June 1989): 254–80; Bruce Murray, *Journey into Space: The First Thirty Years of Space Exploration* (New York, NY: W. W. Norton and Company, 1989), pp. 253–75; and Schorn, *Planetary Astronomy*, pp. 289–90.

134. The United States still ended up being the first nation to visit a comet with a robotic probe. In late 1985, NASA redirected the International Sun-Earth Explorer 3, launched in 1978, to fly through the tail of the lesser-known comet Giacobini-Zinner.

135. The Space Science Board's Committee on Planetary and Lunar Exploration issued several reports in the 1970s on planetary exploration strategies.

136. NASA, "Purpose of Solar System Exploration Committee," November 10, 1980; "Summary Minutes of the SSEC," June 1–2, 1981. Solar System Exploration Committee of the NASA Advisory Council, *Planetary Exploration through Year 2000* (Washington, DC: NASA, 1983), p. 5.

137. Keay Davidson, *Carl Sagan: A Life* (New York: John Wiley and Sons, 1999), p. 348.

In the fall of 1980, the lame-duck Carter Administration included an additional NASA planetary mission in its proposed budget: a Venus Orbiter that would follow up Pioneer Venus by returning radar images of the planet's surface at even better resolution. Called the Venus Orbiting Imaging Radar (VOIR), the mission was Carter's more modest preference to the Halley's Comet rendezvous probe. But Ronald Reagan's triumph in the 1980 presidential election signaled an era of continued difficulty for the solar system exploration program. The Reagan Administration gave NASA $6.1 billion in FY 1982—$604 million less than President Carter had proposed. Office of Management and Budget (OMB) Director David Stockman opted to achieve this budget cut by rescinding the FY 1982 new start on the VOIR mission and instructing NASA to cancel or substantially descope one of its other major space science missions: Galileo, the Hubble Space Telescope, or the U.S.-European International Solar Polar Mission. Much to the chagrin of the Europeans, NASA's Acting Administrator chose to cut the last project, sparing the only planetary mission in development, Galileo.

When the Reagan Administration proposed an even smaller budget for NASA the following fiscal year, NASA's new administrator, James Beggs, announced that the agency would be willing to eliminate its solar system exploration program altogether as long as the Space Shuttle and other space science projects retained adequate funding.[138] [II-31] But after learning in November 1981 that the Administration had cut the agency's budget request by $1.3 billion and reduced solar system exploration funding to $118 million—leaving funds to continue operational missions but none for Galileo's development—Beggs appealed the allocations to a Budget Review Board.[139] [II-32] The White House, however, remained committed to the proposed budget.[140] [II-33] Only in response to a strong push by supporters of planetary exploration and JPL did the White House restore funding for Galileo.[141] Although no funds were restored for VOIR that year, further negotiations between NASA and OMB ultimately brought the FY 1983 solar system exploration budget to $154.6 million, with an additional $92.6 million for Galileo's continued development. NASA would at least be able to sustain a modest planetary program. [II-34]

In 1983 the SSEC recommended a new solar system exploration strategy for NASA. Keeping in mind the need to achieve planetary science goals at reduced costs compared

138. James Beggs to David Stockman, September 29, 1981. Human space flight projects had always been NASA's top priority; the agency was also willing to put space physics and astronomy projects ahead of solar system exploration. Planetary scientists were still a minority group in the space science community; moreover, they were divided on future mission priorities. Space physicists and astronomers, in contrast, agreed that the Great Observatories, such as the Hubble Space Telescope, were their priorities. Logsdon speculates in *The Survival Crisis of the U.S. Solar System Exploration Program*, p. 17, that Beggs said he was willing to cut the planetary exploration program because he figured that the White House would in fact not accept this option. Thus, this as well as other NASA activities would end up receiving funding.

139. NASA, "FY 1983 Budget Appeal," December 5, 1981.

140. Office of Management and Budget, "Summary of OMB / NASA Positions: Space Science and Related Programs (Including Planetary Exploration)," no date; White House, "Selected White House Views (on NASA's planetary exploration program)," December 8, 1981.

141. Many planetary program supporters played upon the political importance of keeping JPL alive as a means to sustain planetary program funding. California Institute of Technology President Marvin Goldberg met with senators interested in the space program in December 1981 and convinced Senate Majority Leader Howard Baker to express his support for planetary exploration in a letter to President Reagan. Baker's letter was influential in the decision to preserve Galileo and the planetary program. Logsdon, *The Survival Crisis of the U.S. Solar System Exploration Program*, p. 35–38.

with the past, the SSEC concluded that NASA should develop a solar system exploration program based on spacecraft in a variety of sizes, but that low- to moderate-cost probes should form the program's core.[142] [II-36] The SSEC believed NASA could sustain a basic planetary program using this strategy for $480 million (FY 00 dollars) per year. As envisioned by the SSEC, the core program would consist of a series of "Planetary Observers"—small spacecraft based on the designs of existing Earth-orbiting probes. These spacecraft would require little in terms of development time and cost, while ensuring that planetary scientists would receive a steady stream of data even if the space agency continued favoring the Space Shuttle or other programs. The first two Planetary Observer missions the SSEC recommended to NASA were a smaller version of the VOIR mission and a Mars orbiter that would focus on the planet's weather patterns. The SSEC also suggested using a modular spacecraft design called the Mariner Mark II for larger missions to the outer solar system, such as its proposed Comet Rendezvous Asteroid Flyby and Titan probe missions.

That year, NASA tried again to push a Venus radar mission through OMB and Congress. Having descoped VOIR and reduced its total cost estimate to under $300 million, the agency was able to gain a new start in the FY 1984 budget for the new mission, now called the Venus Radar Mapper but renamed Magellan in 1986.[143] [II-35] Maintaining the same scientific objectives as VOIR, Magellan would carry, along with two other instruments, a synthetic aperture radar instrument that would return data to make sense of the geological history of the planet's surface and interior. With its original 1988 launch date postponed due to the *Challenger* disaster, the Magellan probe launched from the payload bay of STS-30 on May 4, 1989. Upon arriving at Venus, Magellan embarked on a five-year mission that yielded outstanding scientific results. The spacecraft's returned data enabled scientists to create high-resolution gravity and surface maps of over 95 percent of the planet. Magellan revealed Venus' surface to be covered with volcanoes, faults, impact craters, and lava flows.[144]

The first solar system missions since Pioneer Venus' 1978 departure, the 1989 launches of Magellan and Galileo were the only two missions NASA sent to the planets in the 1980s. During the decade, however, NASA did begin developing three additional solar system exploration missions: one based on the SSEC's Planetary Observer concept, and the two others on the proposed Mariner Mark II spacecraft. The experiences of developing these missions once again indicated to planetary scientists that there still existed a disparity between their interests and the projects that the White House and Congress were willing to fund. In addition, they illustrated the technical and programmatic risks of pursuing very large and ambitious planetary science missions.

---

142. The SSEC made decisions about scientific priorities based on recommendations by the Space Science Board's Committee on Planetary and Lunar Exploration. The SSEC plan is detailed in Solar System Exploration Committee of the NASA Advisory Council, *Planetary Exploration through Year 2000* (Washington, DC: NASA, 1983).

143. NASA Venus Radar Mapper Project Initiation Agreement, October 20, 1982; NASA Program Approval Document for Magellan, September 2, 1988.

144. For more on the scientific achievements of Magellan, see Carolynn Young, ed., *The Magellan Venus Explorer's Guide* (Pasadena, CA: Jet Propulsion Laboratory, 1990) and Peter Cattermole and Patrick Moore, *Atlas of Venus* (New York, NY: Cambridge University Press, 1997).

NASA was able to get a new start for a Mars probe based on the Planetary Observer concept in the same fiscal year in which Congress approved the Venus Radar Mapper.[145] Slated to cost $250 million, the Mars Geoscience/Climatology Orbiter (MGCO) was intended to extend and complement data obtained from the Mariner and Viking Mars spacecraft on the Red Planet's surface composition, atmospheric structure and circulation, magnetic field, and volatile content. To achieve this mission at relatively low cost, the mission planners intended to use proven designs, off-the-shelf components, and simple instruments.

In the end, however, MGCO hardly adhered to the standards the SSEC envisioned for the mission and soon evolved into a Viking-class project.[146] Knowing the low priority NASA had placed on solar system exploration, planetary scientists feared that this Mars mission would be the last to the planet in a great while. They also reasoned that launching on the Space Shuttle would provide "substantial weight and performance margins," and thus spacecraft size and mass were not the concerns they would be if the probe was riding on its own rocket.[147] As a result, those responsible for mission planning selected the most expensive instrument package proposed for the mission. This choice raised the mission's price directly, while also adding to the cost and development schedule because the probe's engineers had to design a more elaborate spacecraft bus than originally intended to accommodate the payload and to reduce the risk of the mission's technical failure. At the time of its launch in 1992, the mission—known by then as Mars Observer—had grown not only in scientific capability but also in cost, to nearly $1 billion—a figure far from that approved years earlier by Congress.[148] Despite the extraordinary measures taken to boost scientific returns and to reduce risk of failure, Mars Observer's potential was never realized; after performing a maneuver to put the spacecraft into orbit around Mars, engineers failed to regain contact with it, making the mission NASA's largest robotic spacecraft failure in history.[149] [II-40]

The SSEC had also recommended in 1983 that NASA undertake the development of a modular spacecraft for outer solar system flight called the Mariner Mark II, whose chassis would contain common control, propulsion, and communications systems to reduce the design costs of missions using it. Beginning in the mid-1980s, NASA studied two Mariner Mark II-based missions—one that would travel to Saturn and release a probe toward its moon Titan, and another that would rendezvous with a comet. In 1989 Congress approved funding in the FY 1990 budget for two solar system explo-

---

145. The Planetary Observer concept was never implemented as a line item in NASA's budget and thus ended with the MGCO/Mars Observer mission.

146. For the history of Mars Observer's development, see Charles Polk, *Mars Observer Project History* (Pasadena, CA: JPL D-8095, December 1990).

147. Solar System Exploration Committee, *Planetary Exploration through Year 2000*, p. 21.

148. Part of the cost increase was due to the need to reconfigure the spacecraft for launch on a different vehicle: after the *Challenger* disaster, NASA opted to fly the Mars Observer on a Titan III booster.

149. The most plausible source of failure, according to the Mars Observer failure report, was that one of the spacecraft's fuel lines ruptured when operators attempted to pressurize the propellant tanks and that this action sent the spacecraft spinning out of control and thus out of communication. Mars Observer Mission Failure Investigation Board, *Mars Observer Mission Failure Investigation Report*, December 31, 1993; NASA, "NASA Response to Mars Observer Loss of Signal Failure Review Board Report," no date. After the report was issued, the investigation board admitted that a hasty management decision might have been the root of the problem. See, for example, Kathy Sawyer, "NASA Admits Oversight on Report," *The Washington Post*, January 11, 1994, p. A 3.

ration missions based on the Mariner Mark II: Cassini and the Comet Rendezvous-Asteroid Flyby (CRAF). The Cassini spacecraft would carry an instrument suite to perform an in-depth survey of the planet Saturn, its rings, and its moons in similar fashion to Galileo at Jupiter. The spacecraft would also release a probe, furnished by the European Space Agency, into the atmosphere of Titan to provide scientists with a first in situ glimpse of Saturn's largest natural satellite. A proposed eight-year mission, CRAF would execute a close flyby of at least one asteroid and then proceed to rendezvous with and fly alongside a comet for a three-year period. Collecting material from the comet's nucleus and dust from its tail, the probe would analyze samples in situ with the objective of characterizing the comet's composition. NASA estimated that developing the missions in tandem, using the Mariner Mark II bus for both probes, would save $500 million over the cost of doing the two separately and would ensure that the agency could meet the $1.5 billion price tag OMB and Congress had set for the two missions' development.[150]

While Cassini and Huygens, the Titan probe, left Earth in 1997 for a 2004 arrival at Saturn, CRAF did not survive beyond the planning stages.[151] [II-38] With tight overall budgets and increasing costs of space station development, NASA assessed its priorities in 1991 and chose first to cut costs by deleting two instruments from the CRAF spacecraft and then to readjust its mission profile and push back its scheduled 1996 launch date.[152] CRAF's doom arrived in FY 1993, when NASA's budget fell ten percent short of its request and the agency completely cancelled the mission in an attempt to save Cassini. The latter mission seemed to NASA to have greater public appeal, due to Saturn's photogenic rings, and more political importance, due to international involvement with the probe.[153] [II-41, II-42] Although NASA had intended to employ an efficient means of developing the two spacecraft, even this measure did not save one of them from cancellation. In spite of the attempt to descope the mission to achieve some of its objectives, this effort only drove CRAF's total cost higher, ultimately sealing its fate and limiting future funding for planetary missions.

Embracing a Leaner Approach to Solar System Exploration in the 1990s

The *Challenger* disaster of 1986 gave NASA the impetus not only to reexamine Space Shuttle policy but also to review its space science program. Reflecting on the elevated costs, delayed development schedules, and increased technical risks associated with recent planetary missions, a committee of NASA advisors concluded that expanding missions' scopes without heeding resource limitations tended in the long

---

150. Space Studies Board, "Scientific Assessment of the CRAF and Cassini Missions," March 30, 1992. The Committee on Planetary and Lunar Exploration wrote this document as a letter report to NASA's Associate Administrator for Space Science, Lennard Fisk.

151. Cassini's greatest opposition was perhaps that of people who protested NASA's launching of the spacecraft for fear that its plutonium power source could rain all over Earth should the spacecraft be destroyed during launch or in passing Earth on its flight path to Saturn.

152. Space Studies Board, "Scientific Assessment of the CRAF and Cassini Missions."

153. The Senate Appropriations Subcommittee decided to eliminate CRAF in the FY 1993 budget. The President's budget for that fiscal year did not include CRAF, and Congress never opted to restore funds for the mission.

run to devastate the solar system exploration program both financially and scientifically.[154] Clearly, the experiences of developing planetary missions in the 1970s and 1980s showed NASA that bigger was not necessarily better for achieving scientific returns, especially when the agency's funds were tight and its priorities were manifold. While in 1989 the Bush Administration endorsed human missions to the Moon and Mars, many of those involved with NASA's robotic solar system exploration program believed that the agency ought to turn to more modest spacecraft.[155] In light of the blows the planetary program had endured over the past years, in 1989 NASA's Space Science Advisory Committee rekindled the idea of a low-cost missions program to maintain the vitality of planetary science, and the space agency finally embraced the concept.[156]

That year, NASA's space science planning committees began serious discussions about a program for low-cost planetary missions.[157] Coming to realize the gravity of the problems facing solar system exploration and recognizing that NASA would endure a gap in the flow of planetary data between the 1997 end of Galileo's mission and Cassini's Saturn arrival in 2004, these groups felt they had little option but to make small planetary missions with short development times a priority.[158] Daniel Goldin's appointment as NASA Administrator in April 1992 lent further support to the concept. Goldin had been an advocate of small and inexpensive, yet potent, space science missions since his days as an engineer at TRW. Once at NASA, he began to preach the gospel of "faster, better, cheaper" missions for all space science disciplines, including planetary science.[159] At the request of the Senate Appropriations Subcommittee to "prepare a plan to stimulate and develop small planetary...projects, emphasizing those which could be accomplished by academic or research communities," NASA delivered a report claiming that solar system exploration missions with low price tags and short development times would become the centerpiece of the agency's new programs in the 1990s.[160] [II-39]

---

154. NASA Space and Earth Advisory Committee, *The Crisis in Space and Earth Science* (Washington, DC: NASA, 1986).

155. In 1987 the NASA Advisory Council recommended that NASA follow robotic exploration of Mars with human visits as a means for the United States to reassert its leadership in space. Shortly afterward, NASA established the Office of Exploration to begin planning the scientific objectives and technological requisites of human missions to the planets. President Bush announced the Space Exploration Initiative in 1989 to send humans back to the Moon and on to Mars. Anticipated to revive NASA as a goal akin to Apollo around which the nation could rally, the initiative failed because it could not conjure the support Bush desired.

156. A year earlier, the Office of Space Sciences and Applications announced its commitment to augment NASA's Explorer program for non-planetary space science missions with small missions. See NASA, *Office of Space Sciences and Applications Strategic Plan* (Washington, DC: NASA, 1988).

157. For an overview of NASA's development of small missions for planetary science, see Stephanie Roy, "The Origin of the Smaller, Faster, Cheaper Approach in NASA's Solar System Exploration Program," *Space Policy* 14 (August 1998): 153–171. For the utility of such missions, see Space Studies Board, *The Role of Small Missions in Planetary and Lunar Exploration* (Washington, DC: National Academy Press, 1995).

158. Galileo's primary mission was scheduled to end in December 1997, but NASA has kept the spacecraft in operation due to its sustained health and remarkable scientific achievements.

159. "Faster, better, cheaper" (or any permutation of the three words) became an important mantra of NASA beginning in the 1990s. In general, it has been used in reference to projects intended to achieve outstanding results using fewer resources and less development time than past projects with comparable objectives.

160. NASA, "Small Planetary Mission Plan: Report to Congress," April 1992.

The program NASA proposed, called Discovery, received a programmatic new start in FY 1994 as a line item in the NASA budget.[161] Similar to the "Small Explorer" concept that had been in place for a few years for small, Earth-orbiting astrophysics and space physics missions, Discovery became the first small planetary missions program to receive its own budget line. NASA Headquarters imposed strict guidelines on Discovery. Under the program, individual scientists could propose entire missions to explore targets in the solar system. Every one to two years, NASA would review the proposals and select one or two to fund, based on their scientific value, cost, technical feasibility, and other factors.[162] The selected missions could cost no more than $170 million (FY 00 dollars), take no more than three years to develop, and launch on a booster no more powerful than a Delta II.[163] As envisioned by NASA, Discovery would not preclude missions to the outer solar system, but would be most appropriate for allowing investigators to conduct missions with focused scientific objectives to small bodies and within the inner solar system. Table 1 lists all of the Discovery missions that NASA has selected to date. Thus far, Discovery missions have demonstrated a new technique to land on Mars and to test the possibility of controlling from Earth a roving vehicle on the surface, and also have returned new data on the Moon's gravitational field and repudiated speculation that water ice exists on its surface.[164] Stressing public education and outreach, mission planners have made efforts to put these missions in the public eye in order to help renew public enthusiasm for solar system exploration.[165]

---

161. During the same year, the Ballistic Missile Defense Organization, with NASA's assistance, launched and operated a small, low-cost spacecraft called Clementine in the vicinity of the Moon to test sensors using advanced technology. Although the mission failed in its second planned task to track a near-Earth asteroid, the mission did help build confidence in NASA that the low-cost mission concept was viable.

162. The Discovery program has followed a competitive selection process for all but its first two missions, the Near Earth Asteroid Rendezvous and the Mars Pathfinder, which were missions in development that were grandfathered into the program to get it started.

163. The cost figure includes the price of design, development, and construction of the spacecraft and the first 30 days of the mission's operation. It does not include the cost of launch. NASA, Office of Space Science, Solar System Exploration Division, *Discovery Program Handbook,* November 1992.

164. For the preliminary scientific results of Mars Pathfinder, see several articles in *Science* 278 (December 5, 1997): 1734–74. For more on Lunar Prospector's search for lunar ice, see NASA Press Release 99–119, "No Water Ice Detected from Lunar Prospector Impact," October 13, 1999.

165. People around the world raved as they saw the first color pictures of the rover taken by the lander after Mars Pathfinder's successful bounce-landing on the Martian surface on July 4, 1997. That JPL's Mars Pathfinder World Wide Web site received a then to-date record of 47 million hits on one of the days shortly following the spacecraft's landing shows that the world took great interest in the Mars mission.

TABLE 1: NASA-APPROVED DISCOVERY MISSIONS

	Selection Year	Launch Date	Mission Description	Status
NEAR (Near-Earth Asteroid Rendezvous)	1993	February 1996	The first spacecraft to orbit and study an asteroid	In progress
Mars Pathfinder	1993	December 1996	Demonstrated a low-cost method of landing a spacecraft and science instruments onto the surface of Mars and using a small rover to explore Martian terrain	Completed
Lunar Prospector	1994	January 1998	Offered insight on the Moon's origin and evolution; also sought to determine whether water ice exists at the Moon's poles	Completed
Stardust	1995	February 1999	Will be the first spacecraft to collect comet and interstellar dust particles and return them to Earth	In progress
CONTOUR (Comet Nucleus Tour)	1997	N/A	Will encounter and study at least three comets	In development
Genesis	1997	N/A	Will collect wind particles to improve understanding of the evolution of the solar system	In development
MESSENGER (Mercury: Surface, Space Environment, Geochemistry and Ranging)	1999	N/A	Will orbit and conduct scientific investigation of Mercury	In development
Deep Impact	1999	N/A	Will probe beneath the internal composition and structure of a comet by crashing a projectile into its surface	In development

NASA embarked on yet another mission series in the 1990s. While Mars Observer was under development, the space agency made plans to establish a long-range program of Mars exploration. Its early concept was the Mars Environmental Survey (MESUR), whose goal was to distribute globally sixteen small landers on the Martian terrain in order to make measurements of the planet's surface, interior, and atmosphere. NASA planners anticipated that emplacing the MESUR network would not only benefit Mars science but also provide experience useful to the agency for developing technology for future robotic and human missions to the Red Planet. The agency hoped to initiate the network in the mid-1990s with a demonstrator lander called MESUR Pathfinder.[166]

Changing programmatic objectives as well as economic constraints, however, led NASA to suspend the MESUR concept, as it seemed likely that the agency would only be able to secure funding in the near future for a few of the project's ground stations. Still determined to create a long-term U.S. presence on and around Mars, NASA proposed another program that would fit better with the "faster, better, cheaper" concept that was becoming more popular and necessary to its programs' sustenance. Called Mars Surveyor, the program would abandon the notion of an integrated network of ground stations; instead NASA would send two low-cost spacecraft—an orbiter and a lander—to Mars every 26 months over the course of ten years.[167] Each mission, cost-capped at $175 million (FY 00 dollars) and limited to three years of development time, would address science objectives centered on understanding Mars' climate, resources, and the search for water and life.[168] By 2005, the agency hoped to send a robotic envoy to the surface that would be capable of collecting samples of Martian terrain and returning them to Earth. With the capability to achieve the scientific objectives of the recently lost Mars Observer, the Mars Surveyor program, to be managed by JPL, won the favor of both the Clinton Administration and Congress. The program received a $77-million new start in the FY 1995 budget and was approved by Congress shortly thereafter.[169] In the government as well as the public, enthusiasm for Mars study burgeoned in August 1996 when a team of planetary science researchers funded by NASA reported that they had found the first organic molecules of Martian origin—possible evidence that life once existed on the Red Planet—in ALH84001, a meteorite found in Antarctica and thought to be descended from Mars.[170] [II-43, II-44, II-45] With a renewed focus on the search for life on Mars, at the end of that year NASA kicked off its new Mars program with the launches of Mars Pathfinder and the Mars Global Surveyor, which arrived at Mars in 1997.[171] [II-46]

---

166. NASA ultimately flew MESUR Pathfinder as a Discovery mission called Mars Pathfinder.

167. Earth and Mars are in a configuration that minimizes the length of travel between the planets once every 26 months.

168. Space Studies Board, *Review of NASA's Planned Mars Program*, (Washington, DC: National Academy Press, 1996), p. 13.

169. The approval of Mars Surveyor marked the fastest entry ever of a NASA program into the federal budget, occurring in less than six months.

170. David S. McKay, Everett K. Gibson, Jr., Kathie L. Thomas-Keprta, Hojatollah Vali, Christopher S. Romanek, Simon J. Clemett, Xavier D. F. Chillier, Claude R. Maechling, and Richard N. Zare, "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001," *Science* 273 (16 August 1996): 924–30.

171. Although Mars Pathfinder was funded through the Discovery program, its activities also supported the goals of the Mars Surveyor program.

While both of these spacecraft safely reached Mars and conducted successful missions, neither of NASA's next two probes in the series achieved any of their science objectives. Launched independently, the Mars Climate Orbiter and the Mars Polar Lander both disappeared as they made their final approaches to the planet. These mishaps have forced the space agency to cancel plans to send a lander to Mars in 2001 and to rethink its approach to managing the Mars program.[172]

Whither the Past and Future of Planetary Exploration?

Ronald Schorn notes in his book-length history of planetary astronomy that "[t]he American space program…galvanized the field of planetary astronomy, revitalized it, and reformed it."[173] Indeed, his words could not be closer to the truth. The establishment of a national space program managed by a civil agency transformed solar system study from what years before was an endeavor of amateurs, whose homemade telescopes only allowed them to see into the cosmos as far as the planets, into a full-fledged scientific discipline worthy of pursuing for its own sake. Providing an organizational structure and armed with abundant federal funds, NASA essentially institutionalized the study of the planets and thus was able to attract geologists, astronomers, and engineers alike to help build up the field. Having become a big science enterprise, planetary astronomy's operations moved into the realm of space—a feat about which scientists for millennia had only dreamed. From the time of NASA's inception, scientists no longer talked only about planetary astronomy or science but planetary *exploration*. Building on technological developments for more than forty years, the space agency has orchestrated a program of robotic explorers that have truly revolutionized human understanding of the solar system.

As this essay has shown, however, the road to scientific success had not always been a smooth one for NASA's solar system exploration program. The task of building spacecraft that can endure long journeys over millions of kilometers of the harsh space environment and successfully return scientific data to Earth indeed has been, and still remains, a daunting technical challenge. But perhaps the even greater challenge to the field has been the constant need to compete with other programs for political and public support to receive funding. Since the end of Apollo, NASA has had a difficult time securing the level of funding it requests each year. Of the programs the space agency manages, human space flight—first Apollo, then the Space Shuttle and the Space Station—has consistently constituted the highest priority. Among the space sciences, solar system missions have experienced greater threats of cancellation than space physics and astrophysics projects because the planetary science community in general has had more difficulty reaching consensus on what research to undertake. NASA planners and scientists have, over time, argued over the relative importance of studying the Moon versus the planets versus smaller bodies such as comets and asteroids. Often, NASA or national needs other than science have governed the activities of the solar system exploration program.

172. Mars Climate Orbiter Mishap Investigation Board, Phase I Report, November 10, 1999; Mars Climate Orbiter Mishap Investigation Board, *Report on Project Management in NASA*, March 13, 2000; Mars Program Independent Assessment Team, *Mars Program Independent Assessment Team Report*, March 14, 2000; JPL Special Review Board, *Report of the Loss of the Mars Polar Lander and Deep Space 2 Missions*, March 2000.

173. Schorn, *Planetary Astronomy*, p. 181.

With budgets diminishing, the Cold War over, and NASA's realization that it cannot afford to sustain ambitious planetary missions, the space agency has turned to small, low-cost spacecraft to perpetuate the program. In light of the recent failures of some Mars spacecraft as well as small spacecraft in other space science disciplines, some scientists and program analysts feel that NASA is jeopardizing missions by imposing overly stringent constraints, reducing oversight of development and operations, and accepting too much risk. Some also believe that the limited resources are forcing small missions to sacrifice scientific capability to ensure their technical integrity. Perhaps solar system missions cannot achieve their scientific potential under reasonable levels of risk on the shoestring budgets and tight development schedules prescribed by the "faster, better, cheaper" strategy.[174]

Now that the solar system exploration program is under scrutiny once again, the space agency must make important decisions to secure the future of its missions to the planets. With over forty years of scientific and technical experience making some of humanity's most extraordinary achievements in the twentieth century, NASA has both the inspiration and capability to ensure planetary exploration's prosperity as the new millennium begins.

****

UNITED STATES SOLAR SYSTEM MISSION SUCCESSES

Spacecraft	Launch Year	Object Studied
Mariner 2	1962	Venus
Ranger 7	1964	Moon
Mariner 4	1964	Mars
Ranger 8	1965	Moon
Ranger 9	1965	Moon
Surveyor 1	1966	Moon
Lunar Orbiter 1	1966	Moon
Lunar Orbiter 2	1966	Moon
Lunar Orbiter 3	1967	Moon
Surveyor 3	1967	Moon
Lunar Orbiter 4	1967	Moon
Mariner 5	1967	Venus
Lunar Orbiter 5	1967	Moon
Surveyor 5	1967	Moon
Surveyor 6	1967	Moon
Surveyor 7	1968	Moon
Apollo 7	1968	Moon
Apollo 8	1968	Moon
Mariner 6	1969	Mars

174. Tony Spear, "NASA FBC Task Final Report," March 2000. In this study requested by NASA Administrator Dan Goldin, Spear's task group expressed the sentiment that NASA's management techniques and resource constraints contributed to the recent solar system mission failures.

UNITED STATES SOLAR SYSTEM MISSION SUCCESSES (continued)

Spacecraft	Launch Year	Object Studied
Mariner 7	1969	Mars
Apollo 9	1969	Moon
Apollo 10	1969	Moon
Apollo 11	1969	Moon
Apollo 12	1969	Moon
Apollo 14	1971	Moon
Mariner 9	1971	Mars
Apollo 15	1971	Moon
Pioneer 10	1972	Jupiter
Apollo 16	1972	Moon
Apollo 17	1972	Moon
Pioneer 11	1973	Jupiter, Saturn
Mariner 10	1973	Venus, Mercury
Viking 1	1975	Mars
Viking 2	1975	Mars
Voyager 1	1977	Jupiter, Saturn
Voyager 2	1977	Jupiter, Saturn, Uranus, Neptune
Pioneer Venus 1	1978	Venus
Pioneer Venus 2	1978	Venus
Magellan	1989	Venus
Galileo	1989	Jupiter and its moons
Clementine	1994	Moon
NEAR	1996	Asteroid
Mars Global Surveyor	1996	Mars
Mars Pathfinder	1996	Mars
Cassini*	1997	Saturn, Titan
Lunar Prospector	1998	Moon

*still en route to destination

NASA's planetary science program is on the right track. The space agency has met or exceeded many of the goals set by the National Academies of Sciences, Engineering and Medicine in the 2013-2022 planetary science decadal survey , according to a new midterm assessment by the National Academies.Â The committee also recommended that "NASA should immediately work to reinvigorate international cooperation to help implement Mars exploration more effectively and affordably." Mars 2020 plays a key role in sample return, though there is no mission currently on NASA's books to retrieve the samples the rover will collect and cache. Place {{NASA planetary exploration programs}} at the end of an article, but above any categories. Initial visibility: currently defaults to autocollapse. To set this template's initial visibility, the |state= parameter may be used: |state=collapsed: {{NASA planetary exploration programs|state=collapsed}} to show the template collapsed, i.e., hidden apart from its title bar. |state=expanded: {{NASA planetary exploration programs|state=expanded}} to show the template expanded, i.e., fully visible. |state=autocollapse: {{NASA planetary exploration programs|state=autocollapse}}.