Deep Space Chronicle:

Foreword

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From the 1950s to the present, to some Americans, space has represented prestige and a positive image for the United States on the world stage. To others, it has signified the quest for national security. Some view it as a place to station telecommunications satellites and little else. To still others, space is, or should be, about gaining greater knowledge of the universe. It represents, for them, pure science and the exploration of the unknown. Even so, the history of space science and technology is one of the largely neglected aspects in the history of the space program. This important monograph by Asif A. Siddiqi chronicles the many space probes that have been sent from Earth to explore other bodies of the solar system. It provides a chronological discussion of all space probes, both those developed by the United States and those developed by the Soviet Union/Russia and other nations; basic data about them; their findings; and their status over time. As such, this monograph is a handy reference work that will provide fundamental data for all missions undertaken during the twentieth century.

Since the first flights discussed here, every planet of the solar system has been explored in a modest way at least once (save Pluto), and several of the moons of planetary bodies (including our own), as well as some comets and asteroids, have been visited. We have placed spacecraft in orbit around our Moon and the planets Venus, Mars, and Jupiter; we have landed on Venus, Mars, and our Moon. NASA's stunning missions to explore the outer Solar System have yielded a treasure of knowledge about our universe, how it originated, and how it works. NASA's exploration of Mars—coupled with the efforts of the Soviet Union/Russia—has powerfully shown the prospect of past life on the Red Planet. Missions to Venus (including some that landed on it) and Mercury have increased our understanding of the inner planets. Lunar exploration has exponentially advanced human knowledge about the origins and evolution of the solar system. Most importantly, we have learned that, like Goldilocks and the three bears, Earth is a place in which everything necessary to sustain life is "just right," while all the other planets of our system seem exceptionally hostile.

Planetary exploration has not taken place by magic. It required visionary leadership, strong-willed management, and persevering execution. Like NASA and other aspects of the space program, it began as a race between the United States and the Soviet Union to see who would be the first to get some sort of spacecraft near the Moon. It expanded in the 1960s when space science first became a major field of study. During that decade, both the United States and the Soviet Union began an impressive effort to gather information on the planets of the solar system using ground-, air-, and space-based equipment. Especially important was the creation of two types of spacecraft, one a probe that was sent toward a heavenly body, and the second an Earth-orbiting observatory that could gain the clearest resolution available in telescopes because it did not have to contend with the atmosphere.

The studies resulting from this new data have revolutionized humanity's understanding of Earth's immediate planetary neighbors. These studies of the planets, perhaps as much even as Project Apollo, captured the imagination of people from all backgrounds and perspectives. Photographs of the planets and theories about the origins of the solar system appealed to a very broad cross section of the public. As a result, NASA had little difficulty in capturing and holding a widespread interest in this aspect of the space science program.

Exploration of the Terrestrial (Inner) Planets

During the 1960s, NASA space science focused much of its efforts on lunar missions with projects Ranger, Surveyor, and Lunar Orbiter. Even so, a centerpiece of NASA's planetary exploration effort in that era was the Mariner program, originated by NASA in the early part of the decade to investigate the nearby planets. Built by Jet Propulsion Laboratory (JPL) scientists and technicians, satellites of this program proved enormously productive in visiting both Mars and Venus.

Mariner made a huge impact in the early 1960s as part of a race between the United States and the Soviet Union to see who would be the first to reach Venus. This goal was more than just an opportunity to beat the rival in the Cold War; scientists in both the United States and the Soviet Union recognized the attraction of Venus for the furtherance of planetary studies. Both the evening and the morning star, Venus had long enchanted humans, and it has done so all the more since astronomers realized that it was shrouded in a mysterious cloak of clouds permanently hiding the surface from view. As a further attraction, it was also the closest planet to Earth and a near twin to this planet in terms of size, mass, and gravitation.

After ground-based efforts in 1961 to view the planet using radar, which could see through the clouds, and after learning, among other things, that Venus rotated in a retrograde motion opposite from the direction of orbital motion, both the Soviet Union and the United States began a race to the planet with several robotic spacecraft. The United States claimed the first success in planetary exploration during the summer of 1962, when Mariner 1 and Mariner 2 were launched toward Venus. Although Mariner 1 was lost during a launch failure, Mariner 2 flew by Venus on 14 December 1962 at a distance of 34,827 kilometers. It probed the clouds, estimated planetary temperatures, measured the charged particle environment, and looked for a magnetic field similar to Earth's magnetosphere (but found none). After this encounter, Mariner 2 sped inside the orbit of Venus and eventually ceased operations on 3 January 1963, when it overheated. In 1967, the United States sent Mariner 5 to Venus to investigate the atmosphere. Both spacecraft demonstrated that Venus was a very inhospitable place for life to exist and determined that the entire planet's surface was a fairly uniform 425 degrees Celsius. This discovery refuted the probability that life—at least as humans understood it—existed on Venus.

The most significant mission to Venus began in 1989 when the Magellan spacecraft set out for Venus to map the surface from orbit with imaging radar. This mission followed the Pioneer Venus 1 spacecraft that had been orbiting the planet for more than a decade and had completed a low-resolution radar topographic map, and Pioneer Venus 2, which had dispatched heat-resisting probes to penetrate the atmosphere and communicate information about the surface, Venus's dense clouds, and the 425°C temperature. It also built on the work of the Soviet Union, which had compiled radar images of the northern part of Venus and had deployed balloons into the Venusian atmosphere. Magellan arrived at Venus in September 1990 and mapped 99 percent of the surface at high resolution, parts of it in stereo. The amount of digital imaging data the spacecraft returned was more than twice the sum of all returns from previous missions. This data provided some surprises, among them the discovery that plate tectonics was at work on Venus and that lava flows clearly showed the evidence of volcanic activity. In 1993, at the end of the mission, NASA's Jet Propulsion Laboratory shut down the major functions of the Magellan spacecraft and scientists turned their attention to a detailed analysis of its data.

Mars has attracted significant attention from the beginning of the space age. An attraction yet to be relinquished by most planetary scientists, Mars prompted many missions. In July 1965, Mariner 4 flew by Mars and took 21 close-up pictures. Mariners 6 and 7, launched in February and March 1969, respectively, each passed Mars in August 1969, studying its atmosphere and surface to lay the groundwork for an eventual landing on the planet. Their pictures verified the Moon-like appearance of Mars and gave no hint that Mars had ever been able to support life. Among other discoveries, these probes found that much of Mars was cratered almost like the Moon, that volcanoes had once been active on the planet, that the frost observed seasonally on the poles was made of carbon dioxide, and that huge plates indicated considerable tectonic activity. Mariner 9, scheduled to enter Martian orbit in November 1971, detected a chilling dust storm spreading across Mars; by mid-October dust obscured almost all of Mars. Mariner 9's first pictures showed a featureless disk, marred only by a group of black spots in a region known as Nix Olympia (Snows of Olympus). As the dust storm subsided, the four spots emerged out of the dust cloud to become the remains of giant extinct volcanoes dwarfing anything on Earth. Olympus Mons, the largest of the four, was 483 kilometers across at the base with a 72-kilometer-wide crater in the top. Rising 32 kilometers from the surrounding plane, Olympus Mons was three times the height of Mt. Everest. Later pictures showed a canyon, Valles Marineris, 4,000 kilometers long and 5.6 kilometers deep. As the dust settled, meandering "rivers" appeared, indicating that, at some time in the past, fluid flowed on Mars. Suddenly, Mars fascinated scientists, reporters, and the public.

Project Viking represented the culmination of a series of missions to explore Mars that had begun in 1964. The Viking mission used two identical spacecraft, each consisting of a lander and an orbiter. Launched on 20 August 1975 from the Kennedy Space Center (KSC), Florida, Viking 1 spent nearly a year cruising to Mars, placed an orbiter in operation around the planet, and landed on 20 July 1976 on the Chryse Planitia (Golden Plains). Viking 2 was launched on 9 September 1975 and landed on 3 September 1976. The primary mission of the Viking project ended on 15 November 1976, eleven days before Mars's superior conjunction (its passage behind the Sun), although the Viking spacecraft continued to operate for six years after first reaching Mars. The last transmission from the planet reached Earth on 11 November 1982.

Since the Viking landings, there have been several missions to Mars seeking to further unlock its mysteries. These were energized in 1996 when a team of NASA and Stanford University scientists announced that a Mars meteorite found in Antarctica contained possible evidence of ancient Martian life. When the 1.9-kilogram, potato-sized rock, labeled ALH84001, was formed as an igneous rock about 4.5 billion years ago, Mars was much warmer and probably contained oceans hospitable to life. Then, about 15 million years ago, a large asteroid hit the Red Planet and jettisoned the rock into space, where it remained until it crashed into Antarctica around 11,000 B.C.E. The scientists presented three compelling, but not conclusive, pieces of evidence that suggest that fossil-like remains of Martian micro-organisms that date back 3.6 billion years are present in ALH84001. These findings electrified the scientific world, but they excited the public just as fully and added support for an aggressive set of missions to Mars by the year 2000 to help discover the truth of these theories.

The United States has undertaken several missions since then, including the hugely popular Mars Pathfinder. After launch in December 1996, it sped to Mars and landed on 4 July 1997. There, a small, 10.4-kilogram robotic rover named Sojourner departed from the main lander and began to record weather patterns, atmospheric opacity, and the chemical composition of rocks washed down into the Ares Vallis flood plain, an ancient outflow channel in Mars's northern hemisphere. Pathfinder returned more than 1.2 gigabits (1.2 billion bits) of data and over 10,000 tantalizing pictures of the Martian landscape. The images from both craft were posted to the Internet, and individuals retrieved information about the mission more than 500 million times through the end of July 1997.

Another mission reached Mars on 11 September 1997, when the Mars Global Surveyor, launched in December 1996, entered orbit. That spacecraft's magnetometer soon detected the existence of a planetary magnetic field. This held important implications for the geological history of Mars and for the possible development and continued existence of life there. Planets like Earth, Jupiter, and Saturn generate their magnetic fields by means of a dynamo made up of moving molten metal at the core. A molten interior suggests the existence of internal heat sources that could give rise to volcanoes and a flowing crust responsible for moving continents over geologic time periods.

These missions, coupled with others, began to create a new portrait of the Martian environment through the analysis of data relating to weather patterns, atmospheric opacity, and the chemical composition of rocks washed down into the Ares Vallis flood plain. Despite significant setbacks to the Mars exploration program with the failure of two missions in 1999, scientific returns from the Mars Global Surveyor reenergized interest in the planet. In what may prove a landmark discovery, scientists announced on 22 June 2000 that features observed on the planet suggested that there may be sources of liquid water at or near the surface. The new images showed the smallest features ever observed from Martian orbit—the size of an SUV. NASA scientists compared those features to those left by flash floods on Earth.

Everyone agreed that the presence of liquid water on Mars would have profound implications for the question of life on Mars. NASA's Associate Administrator for Space Science, Ed Weiler, commented, "If life ever did develop there, and if it survives to the present time, then these landforms would be great places to look." The gullies observed in the images were on cliffs—usually in crater or valley walls—and showed a deep channel with a collapsed region at its upper end and at the other end an area of accumulated debris that appeared to have been transported down the slope. Relative to the rest of the Martian surface, the gullies appeared to be extremely young, meaning they may have formed in the recent past. It is possible, scientists said, that water could be about 90 meters to 400 meters below the surface of Mars. Some scientists have been skeptical of these claims, but all agree that the only way to find out what is truly present is to send additional missions to Mars.

Exploration of the Jovian (Outer) Planets

As the heady spaceflight projects of the 1960s—culminating in the lunar exploration effort—suffered from more constrained budgets in the 1970s, NASA's most ambitious planetary science expedition was hatched amongst its leadership. Once every 176 years, the giant planets on the outer reaches of the solar system gather on one side of the Sun, and such a configuration was due to occur in the late 1970s. This geometric line-up made possible close-up observation of all the planets in the outer solar system (with the exception of Pluto) in a single flight, the so-called "Grand Tour." The flyby of each planet would bend the spacecraft's flight path and increase its velocity enough to deliver it to the next destination. This would occur through a complicated process known as "gravity-assist," something like a slingshot effect, whereby the flight time to Neptune could be reduced from thirty to twelve years.

In 1964, to prepare the way for the "Grand Tour," NASA conceived Pioneers 10 and 11 as outer-solar-system probes. Although severe budget constraints prevented the commencement of the project until the fall of 1968 and forced a somewhat less ambitious effort, Pioneer 10 was launched on 3 March 1972. It arrived at Jupiter on the night of 3 December 1973, and while many were concerned that the spacecraft might fall prey to intense radiation discovered in Jupiter's orbital plane, the spacecraft survived, transmitted data about the planet, and continued on its way out of the solar system, away from the center of the Milky Way galaxy. By May 1991, it was about 52 astronomical units (AU) from Earth, roughly twice the distance from Jupiter to the Sun, and still transmitting data.

In 1973, NASA launched Pioneer 11, providing scientists with their closest view of Jupiter, from 42,800 kilometers above the cloud tops in December 1974. The close approach and the spacecraft's speed of 172,800 kph, by far the fastest ever reached by an object from Earth, hurled the Pioneer 11 spacecraft 2.4 billion kilometers across the solar system. In 1979, Pioneer 11 encountered Saturn, closing to within 20,900 kilometers of the planet, where it discovered two new moonlets and a new ring and charted the magnetosphere, its magnetic field, its climate and temperatures, and the general structure of Saturn's interior. In 1990, it officially departed the solar system by passing beyond Pluto and headed into interstellar space toward the center of the Milky Way galaxy. Both Pioneers 10 and 11 were remarkable space probes; they stretched a thirty-month design life cycle into a mission of more than twenty years and returned useful data, not only about the other Jovian planets of the solar system, but also about some of the mysteries of the interstellar universe.

Meanwhile, NASA technicians prepared to launch what became known as Voyager. Although the four-planet mission was known to be possible, it quickly became too expensive to build a spacecraft that could go the distance, carry the instruments needed, and last long enough to accomplish such an extended mission. Thus, the two Voyager spacecraft were funded to conduct intensive flyby studies only of Jupiter and Saturn, in effect repeating on a more elaborate scale the flights of the two Pioneers. Even so, the spacecraft builders designed as much longevity into the two Voyagers as possible with the $865-million budget available. NASA launched these from Cape Canaveral, Florida; Voyager 2 lifted off on 20 August 1977, and Voyager 1 entered space on a faster, shorter trajectory on 5 September 1977.

As the mission progressed, with the successful achievement of all its objectives at Jupiter and Saturn, additional flybys of the two outermost giant planets, Uranus and Neptune, proved possible—and irresistible—to mission scientists. Accordingly, as the spacecraft flew across the solar system, remote-control reprogramming was used to prepare the Voyagers for the greater mission. Eventually, between them, Voyager 1 and Voyager 2 explored all the giant outer planets, forty-eight of their moons, and the unique systems of rings and magnetic fields those planets possess.

The two spacecraft returned information to Earth that revolutionized solar system science, helped to resolve some key questions, and raised intriguing new ones about the origin and evolution of the planets. The two Voyagers took well over 100,000 images of the outer planets, rings, and satellites, as well as millions of magnetic, chemical spectra, and radiation measurements. They discovered rings around Jupiter, volcanoes on Io, shepherded satellites in Saturn's rings, new moons around Uranus and Neptune, and geysers on Triton. The last sequence of images was Voyager 1's portrait of most of the solar system, showing Earth and six other planets as sparks in a dark sky lit by a single bright star, the Sun.

It was nearly two decades after Voyager before any spacecraft ventured to the outer solar system again. In October 1989, NASA's Galileo spacecraft began a gravity-assisted journey to Jupiter and sent a probe into the atmosphere that observed the planet and its satellites for several years beginning in December 1995. Jupiter was of great interest to scientists because it appeared to contain material in its original state left over from the formation of the solar system, and the mission was designed to investigate the chemical composition and physical state of Jupiter's atmosphere and satellites. Because of a unique orbital inclination that sent the probe around the Sun and back on the way to Jupiter, Galileo came back past both Venus and Earth, made the first close flyby of asteroid Gaspra in 1991, and provided scientific data on all. But the mission was star-crossed. Soon after Galileo's deployment from the Space Shuttle, NASA engineers learned that Galileo's umbrella-like high-gain antenna could not be fully deployed. Without this antenna, communication with the spacecraft was both more difficult and more time-consuming, and data transmission was greatly hampered. The engineering team that worked on the project tried a series of cooling exercises designed to shrink the antenna central tower and enable its deployment.

In mid-1995, Galileo deployed the probe that would parachute into Jupiter's dense atmosphere. The two spacecraft then flew in formation the rest of the way to Jupiter, and while the probe began its descent into the atmosphere, the main spacecraft went into a trajectory that placed it in a near-circular orbit. On 7 December 1995, the probe began its descent. Its instruments began relaying data back to the orbiter about chemical composition; the nature of the cloud particles and structure of the cloud layers; the atmosphere's radiative heat balance, pressure, and dynamics; and the ionosphere. The probe lasted for about 45 minutes, during which it stored and returned the data, before the atmosphere and the pressure of the planet destroyed it. For months thereafter, because the high-gain antenna was inoperative, scientists and technicians coaxed the data back to Earth for analysis. Today, Galileo continues to transmit scientific measurements back to Earth. The result has brought a reinterpretation of human understanding about Jupiter and its moons.

Most significant in terms of results has been the discovery of a frozen ocean of water covering Europa, one of the principal moons of Jupiter. On 13 August 1996, data from Galileo revealed that Europa may harbor "warm ice" or even liquid water—a key element in life-sustaining environments. Many scientists and science fiction writers have speculated that Europa—in addition to Mars and Saturn's moon Titan—is one of the three planetary bodies in this solar system that might possess, or may have possessed, an environment where primitive life existed. Galileo's photos of Europa were taken during a flyby of Ganymede some 154,500 kilometers away from Europa. They revealed what appeared to be ice floes similar to those seen on Earth's polar regions. The pictures also revealed giant cracks in Europa's ice where warm-water "environmental niches" may exist. In early 1997, Galileo discovered icebergs on Europa, a discovery that lent credence to the possibility of hidden, subsurface oceans. These findings generated new questions about the possibility of life on Europa. While NASA scientists stressed that the data did not conclusively prove anything, they thought the images exciting, compelling, and suggestive. They called for a concerted effort to send a lander to Europa to burrow through the ice to reach water beneath.

NASA's 2000–01 Near Earth Asteroid Rendezvous (NEAR) mission to the asteroid Eros achieved excellent results. NEAR was the first spacecraft to orbit an asteroid. In one year it met all of its scientific goals while orbiting the asteroid Eros, and then it undertook a controlled descent to the surface of the asteroid on 12 February 2001. The chief goal of the controlled descent was to gather close-up pictures of the boulder-strewn surface of 433 Eros, more than 315.4 million kilometers from Earth. During its five-year, 3.2-billion-kilometer journey, the NEAR mission provided the most detailed profile yet of a small celestial body. It began a yearlong orbit of Eros on 14 February 2000 and collected ten times more data than originally planned. The data include a detailed model culled from more than 11 million laser pulses; radar and laser data on Eros's weak gravity and solid but cracked interior; x-ray, gamma-ray, and infrared readings on its composition and spectral properties; and about 160,000 images covering all of the 34-kilometer bouldered, cratered, dusty-terrain asteroid.

Finally, in 1997, NASA launched the Cassini spacecraft on its voyage to Saturn. In some respects a sister spacecraft to the remarkable Galileo vehicle at Jupiter, this spacecraft will linger for several years collecting all manner of data about Saturn and its moons. Once it arrives in 2003, Cassini is expected to provide a similar level of stunning scientific data about the Saturnine system to the rich harvest that Galileo brought to the human race about Jupiter and its moons.

Conclusion

The Deep Space Chronicle provides a ready reference of deep space missions attempted since the opening of the space age in 1957 and documents the development, testing, and implementation of robotic spacecraft. Here are a few of its features:

- A list of significant "firsts" takes readers from the American Able 1 lunar probe in August 1958, to the Russian Mars 2 spacecraft impact on Mars in November 1971, to the American Sojourner's wheeled touchdown on Mars in 1997, to the American NEAR spacecraft orbit of Eros in February 2000.

- A discussion, with results, of planet flybys introduces attempts on Mars, Jupiter, Saturn, Uranus, and Neptune.

- A detailed bibliography is enclosed, and the author highly recommends Andrew Wilson's *Solar System Log* for more details regarding particular missions.

We are pleased to publish Asif A. Siddiqi's monograph on all planetary missions undertaken during the twentieth century. He is also the author of the recently published pathbreaking book *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (NASA SP-2000-4408). He has created in *Deep Space Chronicle* a factual reference source that will prove useful to all who are interested in planetary exploration.

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