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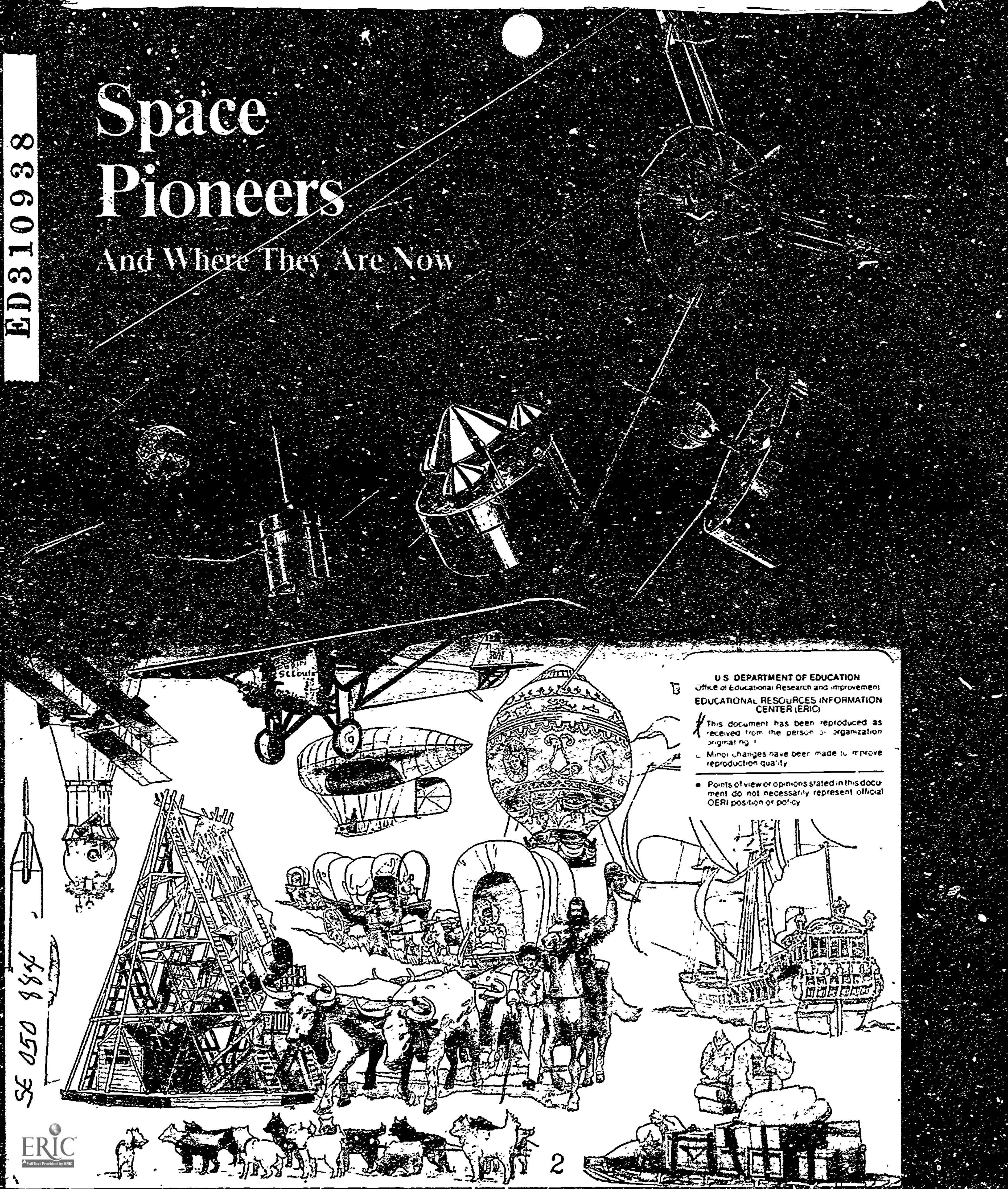
ABSTRACT

This booklet describes the Pioneer Program and its role in exploring the solar system. Sections include: (1) "Pioneers in Space to Understand Our Earth" (describing the background of the program); (2) "First Pioneers"; (3) "The Interplanetary Pioneers"; (4) "Planetary Pioneers"; (5) "Outer Solar System Pioneers"; (6) "The Pioneers Now and In the Future"; (7) "The Pioneer Spacecraft" (listing the launch date, mission, and status of 13 Pioneers); and (8) "Pioneer Firsts" (describing the first discovery and performance by the Pioneer Program). Many diagrams and photographs are provided. (YP)

Space Pioneers

And Where They Are Now



NASA EP-264

Space Pioneers

And Where They Are Now

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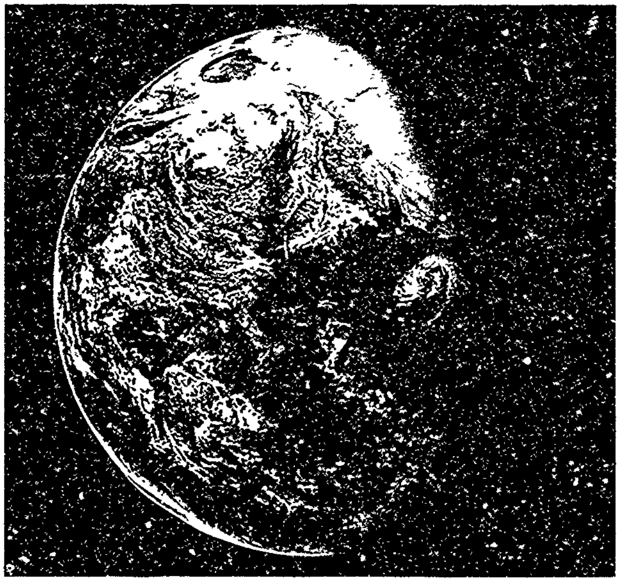
'0 Spacecraft

Pioneers In Space To Understand Our Earth

The great excitement of any age has been created by pioneers — those who sought out new lands, new ideas, new social systems, new forms of governance, new technologies, and new goals for humankind.

In our time we have been privileged to witness an outstanding human achievement of pioneers probing space; the new frontier. This frontier initially begins with the space environment beyond the fringes of Earth's atmosphere, then extends into the space between Earth and the orbit of the Moon, next into the inner Solar System, and with current exploration, into the outer Solar System and beyond.

As sailing ships characterized Columbus pioneering the discovery of the New World, as the covered wagon "prairie schooners" characterized the exploration of the West, we now have spacecraft to characterize the exploration of space frontiers. This modern exploration involved large team efforts of many people; including clerks, secretaries, technicians, engineers, scientists, and managers. Engineers became deeply involved in the challenging development of these highly reliable spacecraft. New techniques for remote control of spacecraft operations and for communicating over many millions of miles of space were devised to achieve the objectives. Scientists devised new ways to make experiments at enormous distances from Earth.



View of Earth from space centered on California

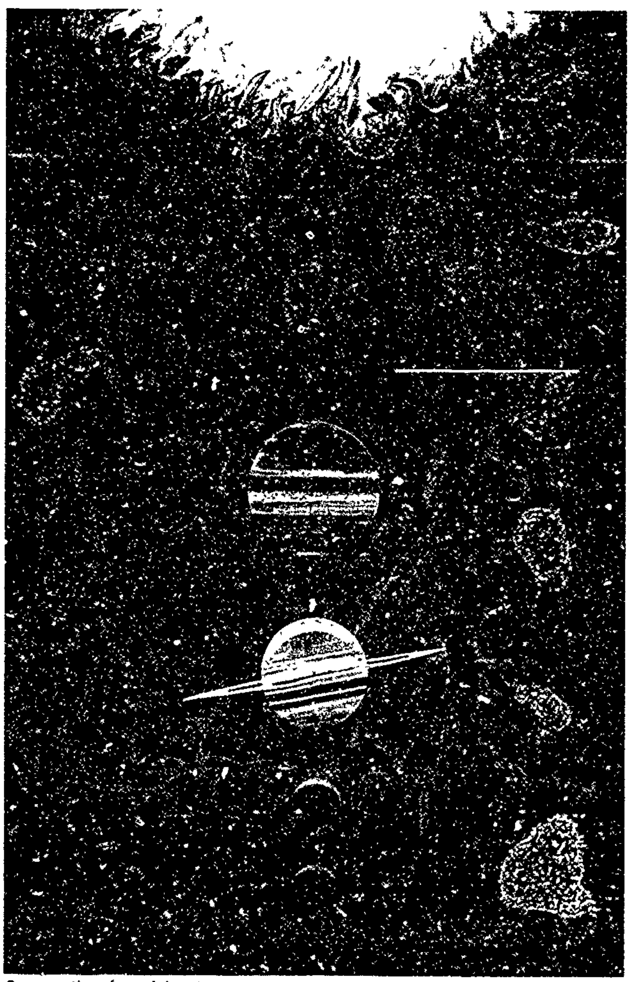
Objectives of these pioneering activities have been to broaden human knowledge of the environment of the Solar System of which our Earth is a member planet, and to try to understand more about how this environment affects life on Earth, its past and its future. To do so, scientists needed to know how the Sun affects the environment in the space containing the planets (the interplanetary environment), how energetic particles — protons and electrons — and radiation from the Sun spread through space to the planets, how the planets are affected by these solar influences and what happens at different times during the 11-year solar activity cycles and the occurrence of individual storms on the Sun, and

Terrestrial aurora as seen from Skylab

how the other planets are affected compared with Earth. Scientists also want to know how far the influence of the Sun extends into space as a heliosphere and how and where the interstellar environment — the character of space containing the stars — becomes predominant. This is important to our understanding of how we on Earth might be affected by events occurring in the galaxy of stars and dust and gas clouds beyond our Solar System.

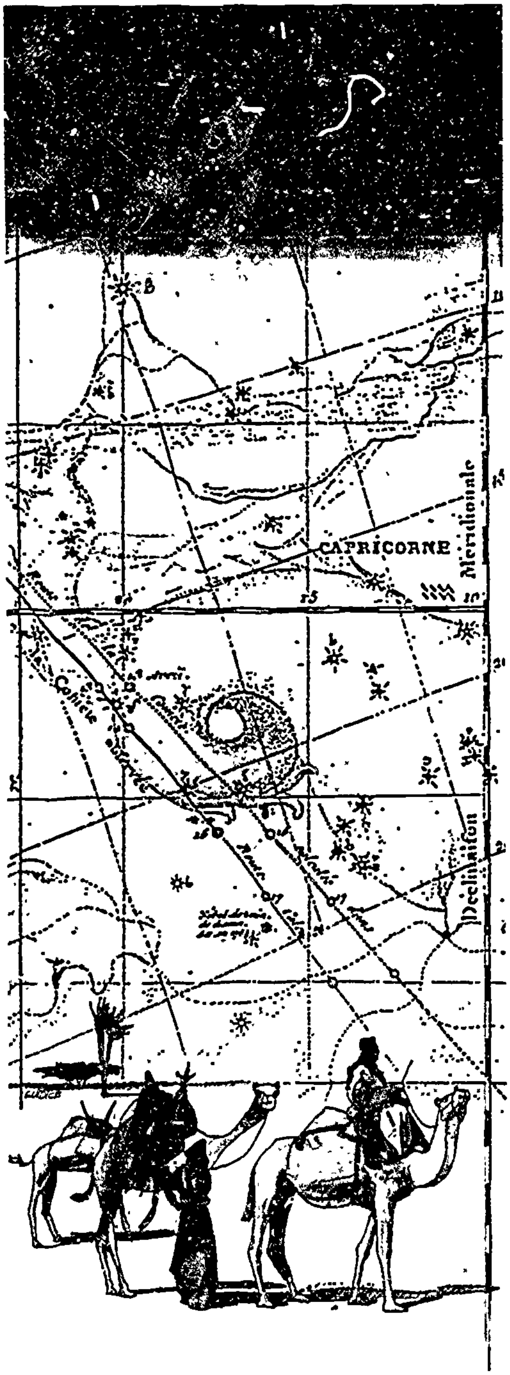
Four groups of pioneering spacecraft have made, and continue to make, significant progress in the exploration of the near space frontier and the achievement of these objectives. These spacecraft started with Pioneers 1 through 5, which made the first thrusts into space toward the Moon and into interplanetary orbit. They continued with Pioneers 6 through 9, which explored inward and outward from Earth's orbit. The Pioneer Venus Multiprobe (Pioneer 13) pushed to the incredibly hot surface of Venus, the errant twin of Earth, and the Pioneer Venus Orbiter (Pioneer 12) surveyed that intriguing planet from orbit for many years. Pioneers 10 and 11, which blazed a trail through the asteroid belt and were first to explore Jupiter, Saturn, and the outer Solar System, are currently seeking the borders of the heliosphere, and will ultimately journey to the distant stars.

Many of these Pioneers have operated far beyond the period expected of them in their original concept and design. The initial relatively small investments have brought a priceless wealth of new information to our national resource of basic knowledge. Several of the spacecraft can productively continue gathering more important data for many years to come. All we need to do to harvest benefit from this continued pioneering is to keep watch over some of these spacecraft, direct their attention periodically to new targets of opportunity, and receive and process the information being sent back to us.



Comparative sizes of the planets and the Sun

First Pioneers

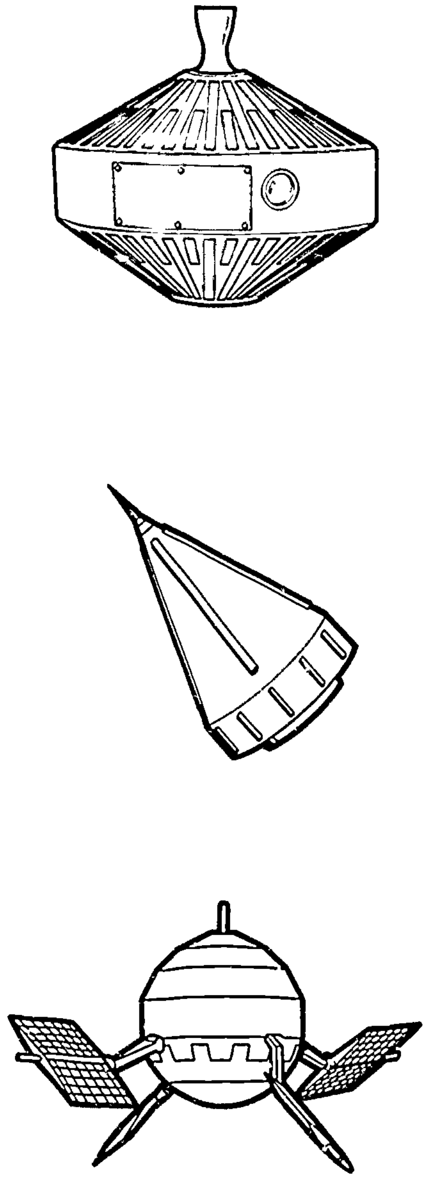


The first program to initially explore the "near" space frontier consisted of a group of Pioneer spacecraft initiated by the Advanced Research Projects Agency of the Department of Defense in 1958 when it authorized five launches toward the Moon. Three spacecraft were the responsibility of the Air Force, and two the responsibility of the Army. As part of the nation's contribution to the International Geophysical Year, these lunar probe Pioneers were intended to gather data from beyond the fringes of Earth's atmosphere. Additionally, they were intended to develop a technology to reach escape velocity from the gravitational pull of Earth and to navigate a spacecraft to the vicinity of another world — namely, the Moon — as a prelude to interplanetary missions.

By 1958 a few Earth-orbiting spacecraft had been successfully launched. Sputniks I and II and Explorer. They showed that surrounding Earth is a very complex region of magnetic fields and high-energy charged particles. As a result there was great interest in exploring this dynamically changing environment to much greater distances from Earth. Earlier concepts of an uninteresting vacuum of space had rapidly changed to accept an involved and dynamic structure of the space environment, an extremely active region of particles and electromagnetic fields interacting with each other and with the planets in then poorly understood ways.

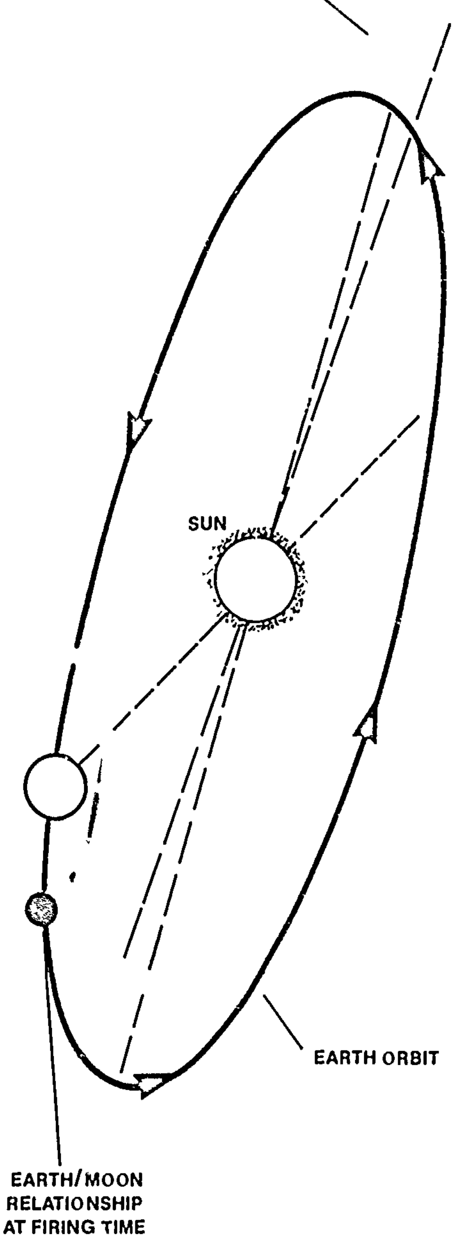
These Pioneers were launched with varying measures of success. On October 11, 1958, Pioneer 1 attained a distance of 72,765 miles from Earth before falling back to Earth. A magnetometer carried by the spacecraft revealed for the first time complex geomagnetic effects thousands of miles from Earth. Pioneer 2 reached only 963 miles from Earth on November 8, 1958. Pioneer 3, under the management of the newly formed National Aeronautics and Space Administration, reached 63,580 miles on December 6, 1958, before falling back to Earth. Pioneer 4, launched on March 3, 1959, reached escape velocity, passed within 37,300 miles of the Moon, and went into orbit around the Sun. Another lunar probe, Pioneer 5, was launched on March 11, 1960, and entered an orbit around the Sun on a mission to explore space to the maximum range of communications available at that time.

All these spacecraft made important discoveries about the extent and form of the Earth's magnetosphere, the region relatively close to Earth where the Earth's magnetic field deflects the solar wind's blizzard of electrons and protons and traps some of these energetic particles to create radiation belts. These discoveries led to intriguing new questions which required a more advanced type of spacecraft capable of exploring space to considerable distances within and beyond Earth's orbit. There followed the Interplanetary Pioneers 6 through 9, designed to explore the environment of Earth's orbit, to investigate the solar wind and its effects on Earth, to observe the interplanetary medium closer to, and further from, the Sun, and to define the important role of particles and fields in their interactions with the planets.



First Pioneers: top to bottom, Pioneer 1, Pioneer 4, and Pioneer 5

way into space



The Interplanetary Pioneers

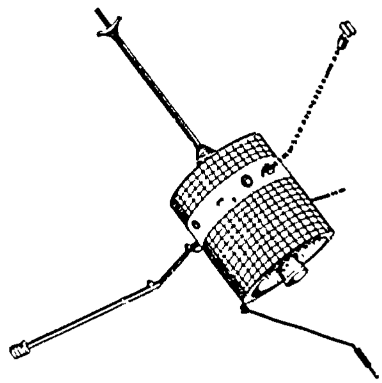
Five spacecraft were planned, all virtually identical and spin-stabilized, and each designed to operate in space for at least 180 days; i.e., approximately half an orbit around the Sun. Pioneer 6 left Earth successfully on December 16, 1965, Pioneer 7 on August 17, 1966, Pioneer 8 on December 13, 1967 and Pioneer 9 on November 8, 1968. The fifth spacecraft was lost because of a Delta launch vehicle failure.

These Pioneers demonstrated the practicality of spinning the spacecraft to stabilize it and to simplify control of its orientation. Measurements made by these spacecraft greatly increased our knowledge of the interplanetary environment and the effects of solar activity on Earth. New information was gathered about the solar wind, solar cosmic rays, the structure of the Sun's plasma and magnetic fields, the physics of particles in space, and the nature of storms on the Sun which produce solar flares. Important incidental results were a more accurate measurement of the mean distance of Earth from the Sun, referred to as the astronomical unit (AU), and more accurate measurement of the masses of the Earth and Moon. Additionally, the spacecraft demonstrated high reliability by operating successfully for many years beyond their design lifetime.

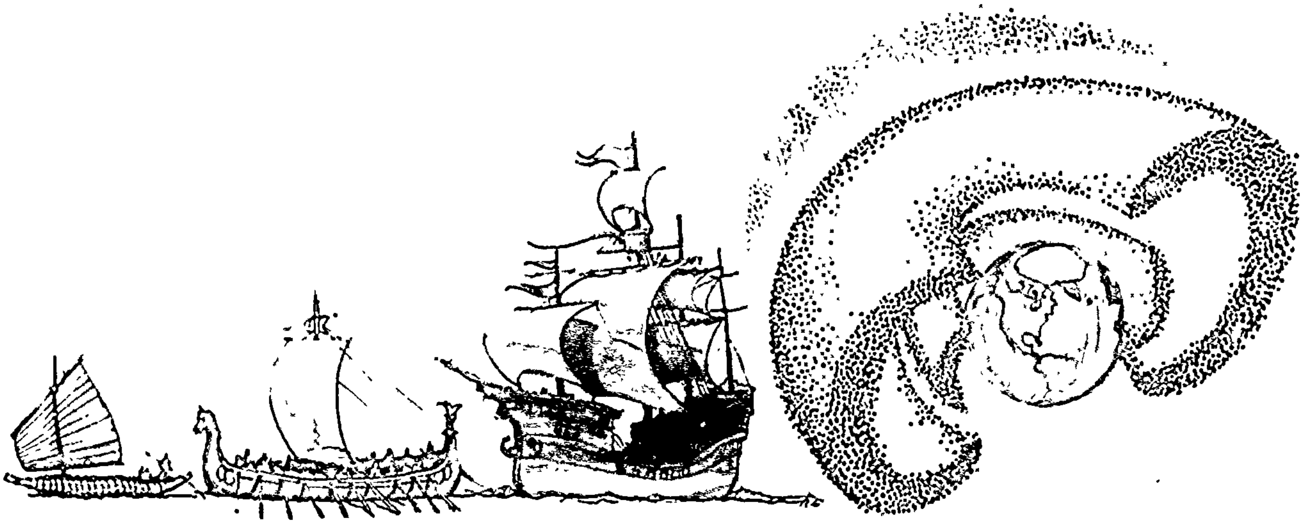
Pioneers 6 and 9 traveled along orbits which carried them inward to a distance of 0.8 AU from the Sun, Pioneers 7 and 8 moved away from the Sun to a distance of 1.1 AU, to explore the region of the Earth's magnetotail and wake, streaming like a pennant away from the Sun. When Pioneers 7 and 8 explored the magnetic tail of the Earth, they discovered well-ordered characteristics but with discontinuities at great distances from Earth.

At the beginning of the space age there had been a belief that cosmic dust could present a serious hazard to spacecraft. The Pioneers proved this fear to be unwarranted. Also, these spacecraft recorded the numbers of different types of cosmic rays and showed how they vary with the solar cycle.

The structure of the interplanetary magnetic field was discovered, pulses of solar protons from the outburst of flares on the Sun were recorded, and short-term changes in the Earth's magnetic field in space were discovered. The spacecraft also identified cosmic rays of Galactic origin and found a striking anisotropy (directional organization) of cosmic rays of low energies compared with those of high energies. It was found that the low-energy cosmic rays come mainly from the Sun even at the minimum of solar activity.

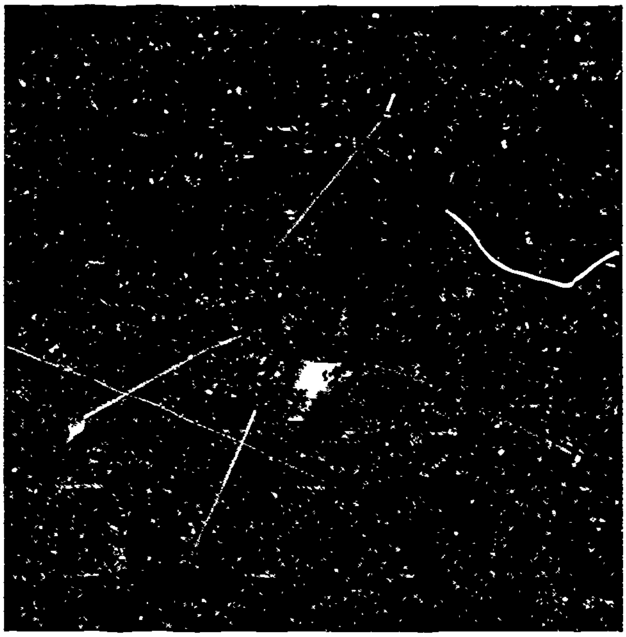


PIONEER 6-9
(1965-1968)

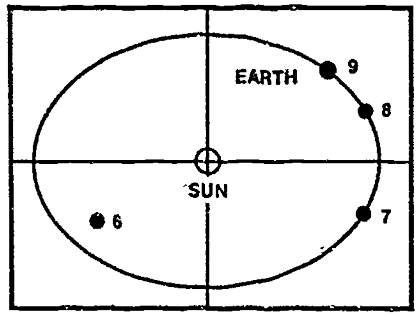


Before Pioneer 6, few spacecraft were capable of making detailed measurements of the solar wind. The Pioneers discovered an east-west asymmetry of the solar wind. The wind was described as spiraling from the Sun, analogous to a rotating water sprinkler. The Pioneers were first to show that its direction and speed could be recorded and studied.

Radio signals sent from Earth to the spacecraft checked the propagation of radio waves through space and how this propagation is affected by storms on the Sun. Detailed studies were made on the plasma clouds ejected from the Sun by solar flares. The shapes and extent of plasma clouds passing by the Earth were determined. Passage of radio waves through the solar corona was also investigated for the first time as Pioneer spacecraft were occulted (passed behind the Sun).



Interplanetary Pioneer 6-9 spacecraft



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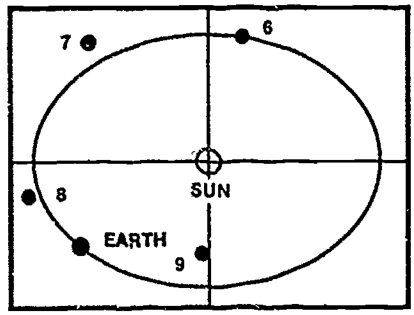

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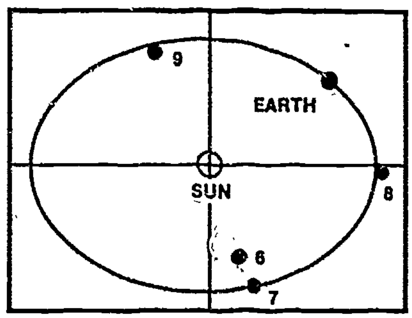

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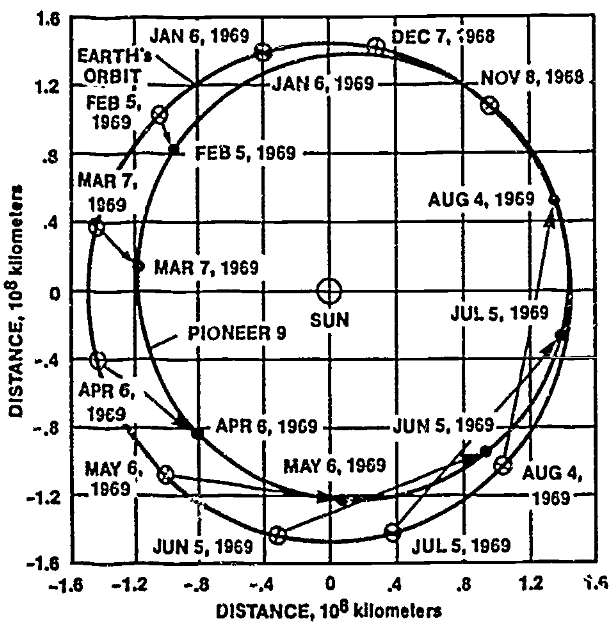
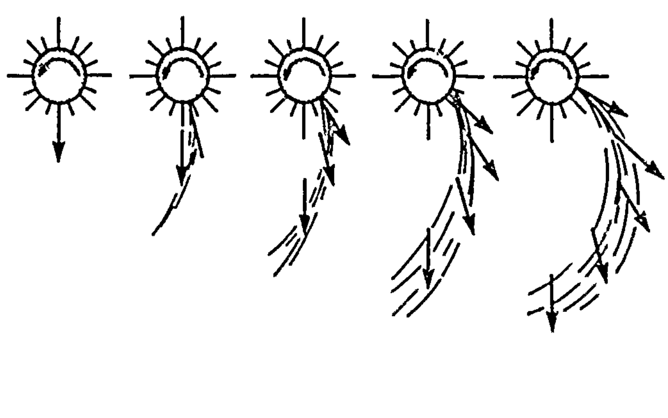
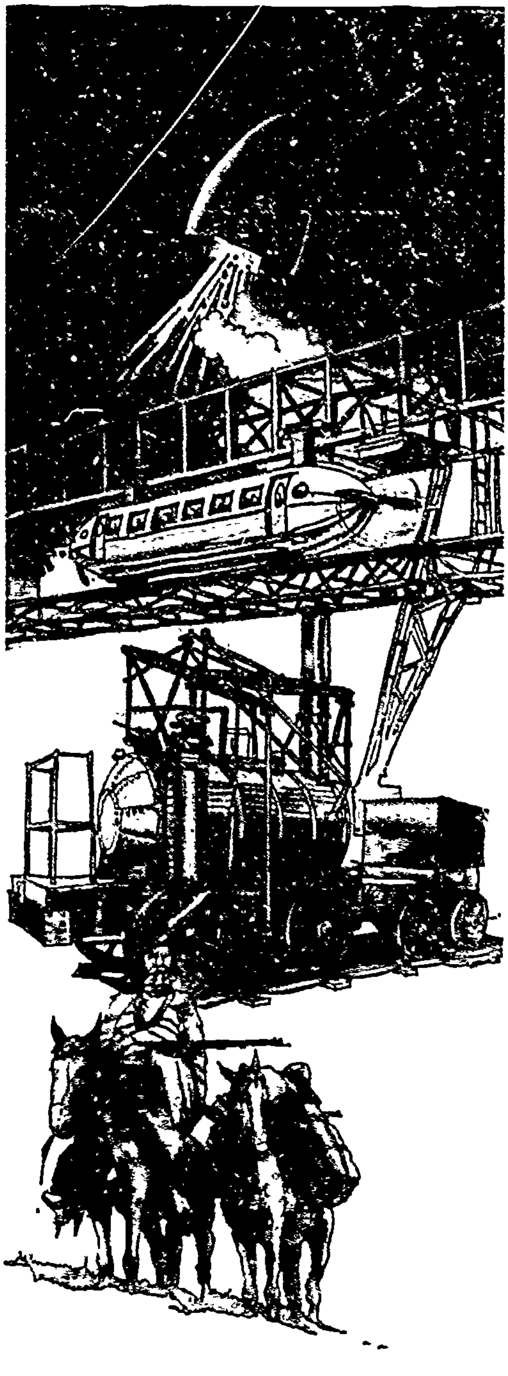
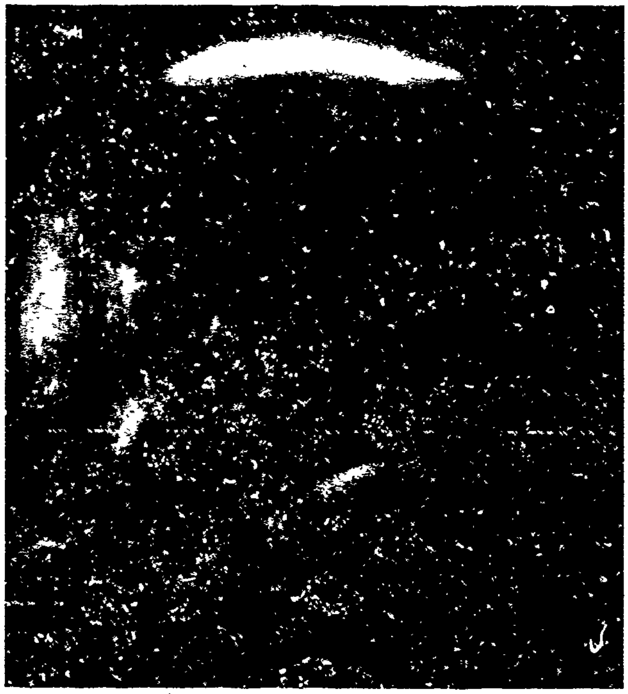




neers mapped the solar wind patterns

Planetary Pioneers

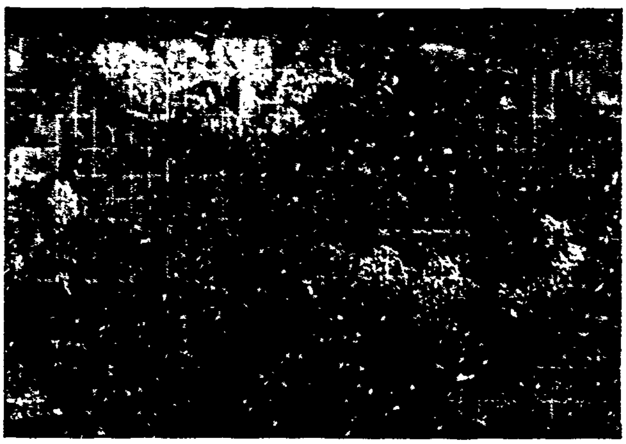




Planet Venus imaged from Pioneer Venus

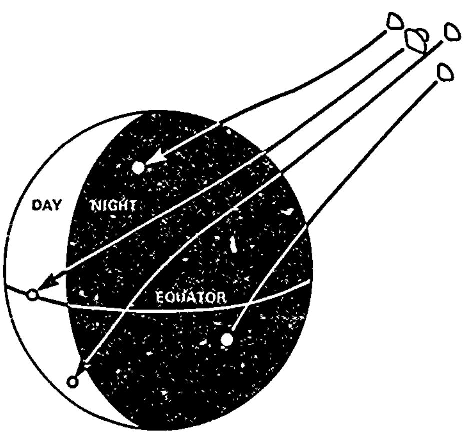
In size Venus is the closest planet to being Earth's twin; but it is an errant twin that has evolved into a very inimical world from the standpoint of living things. The study of Venus has deep implications for understanding our own planet. We need to know why and how Earth evolved benignly from the primordial solar nebula for life to evolve upon it and continue to be supported by it. With the growing awareness of long-term environmental effects on Earth, scientists wanted to know much more about Venus and its meanings for Earth, why Venus is so different, why it should have such a strange atmosphere — 100 times as dense as Earth's — that shields the planet's surface from direct Earth-based observation at wavelengths of visible light, why its surface is hot enough to melt lead, and why the planet lacks significant amounts of oxygen and water. If Venus had oceans, where did they go?

The Pioneer Venus program was designed to investigate this mysterious planet in detail. The Pioneer 13 multiprobe spacecraft dispatched heat-resisting probes to penetrate the atmosphere and radio back to Earth in-situ measurements from the upper atmosphere, through



Topographic map of Venus obtained by Pioneer Venus Orbiter, Pioneer 12

Artist's rendering of Pioneer probe entering the atmosphere of Venus



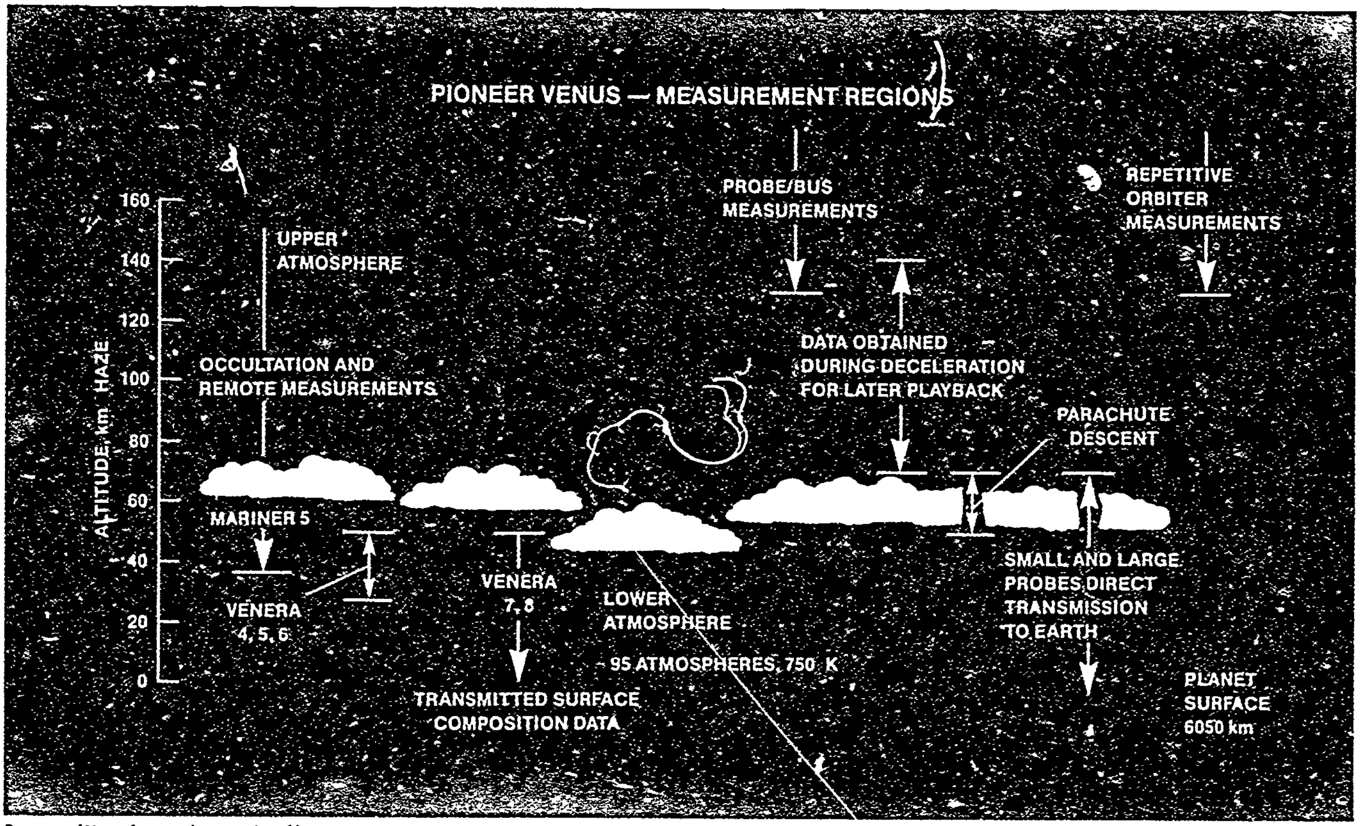
the dense clouds, and down to the 900° F surface. An Orbiter (Pioneer 12) circles Venus to this day and has mapped its hidden surface by radar, imaged its changing cloud systems, explored its unique magnetic environment, and observed the interactions of the solar wind with a planet that has no intrinsic magnetic field.

The four probes plunged into the atmosphere at widely separated locations in day and night hemispheres. They measured temperature, pressure, and density down to the planet's surface. They discovered diurnal changes in the upper atmosphere and found that at high altitudes Venus' atmosphere is cooler and at low altitudes much hotter than Earth's. The temperature below the clouds was found to be relatively constant at a given height everywhere on the planet. Instead of turbulence, unexpectedly stable atmospheric layers were found below the clouds.

The probes charted vertical winds and determined the chemical composition of the atmosphere. It is mainly carbon dioxide and nitrogen but, unlike Earth, it has very little oxygen or water vapor. Rare atmospheric gases and their isotopes were detected and their concentrations were measured. Unexpectedly, there were high abundances of neon and of argon 36 and 38 isotopes, which leads us to conclude that Venus and Earth received different original volatiles from the solar nebula out of which the planets are believed to have formed.

The ratio of deuterium to hydrogen is 100 times as large as that in Earth's oceans, which suggests that there has been a preferential escape of a large amount of hydrogen from Venus. This is evidence that Venus probably had a large quantity of water, perhaps as much as an ocean, sometime during its history. The ocean may have been lost because a "greenhouse" effect trapped solar heat in Venus' atmosphere so that the planet became too hot to retain water on its surface.

A Pioneer Probe spacecraft on the surface of Venus



Regions of Venus' atmosphere explored by spacecraft

The Orbiter's radar provided altimetry maps for nearly all of the surface of Venus, resolving features down to about 50 miles across. On these maps, scientists identified volcanoes that may still be active, continental areas with great plains and mountain ranges in which one peak rises 35,500 feet, island masses rising from global plains; rift valleys such as Diana Chasma, which is 9,500 feet deep; some craters, and extensive areas of global plains with relatively flat and monotonous surfaces. Key features on Venus have been and will continue to be named after women, e.g., Aphrodite, Freyja, Asteria, Atla, Ishtar, Atalanta, Phoebe, Themis, and Leda. Venus was found to be a planet that is closer to being a sphere than are Earth and other planets, as might be expected from its slow rotation, which is 242 times slower than Earth's.

Pioneer Venus' radar altimetry data were used to select targets for subsequent U.S.S.R. Venus probes. Important international cooperation has been enhanced by exchanges of information about Venus.

Sensitive and detailed measurements of spacecraft accelerations in orbit show that mountainous formations are less dense than the global crust, and that, as on Earth, they appear to be supported on a liquid interior.

Movements of masses of the atmosphere, charted in observations made from orbit, revealed global winds of 220 mph at the cloud tops. These winds generally blow ...stward, with virtually no motions north or south.

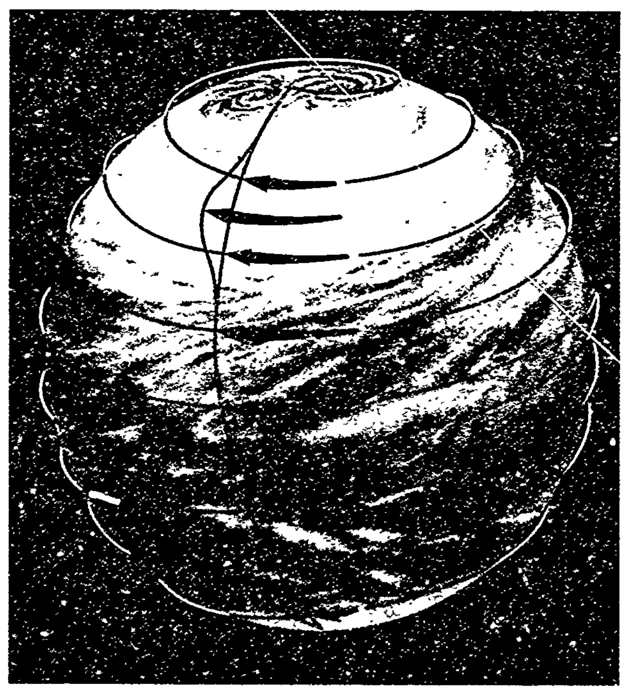


Diagram of global winds in the atmosphere of Venus as charted by Pioneer spacecraft

Electrical signals from Venus detected by Pioneer are possibly caused by lightning flashes in gas clouds arising from active volcanoes. If these emissions are not caused by lightning in such clouds they present a problem because there is no other terrestrial counterpart to explain them.

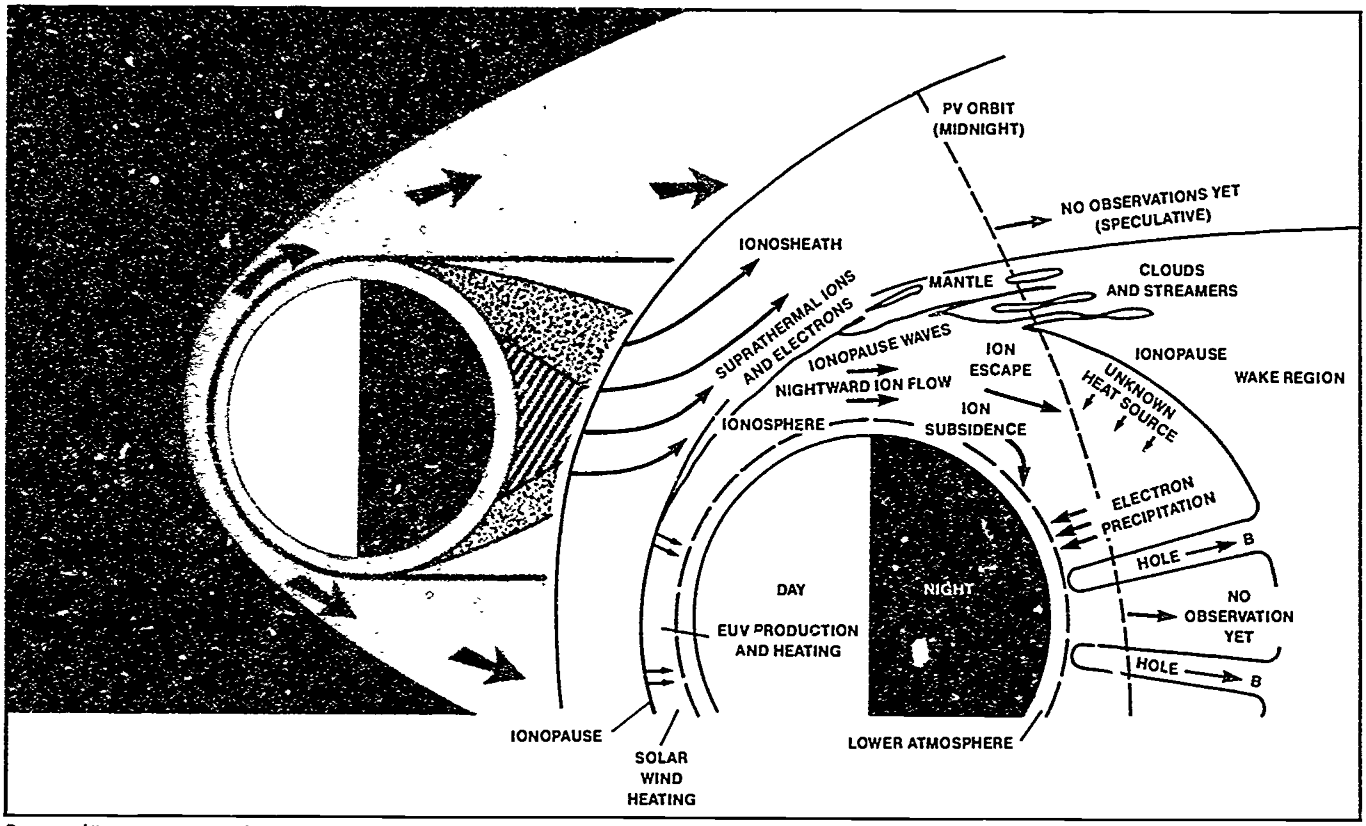
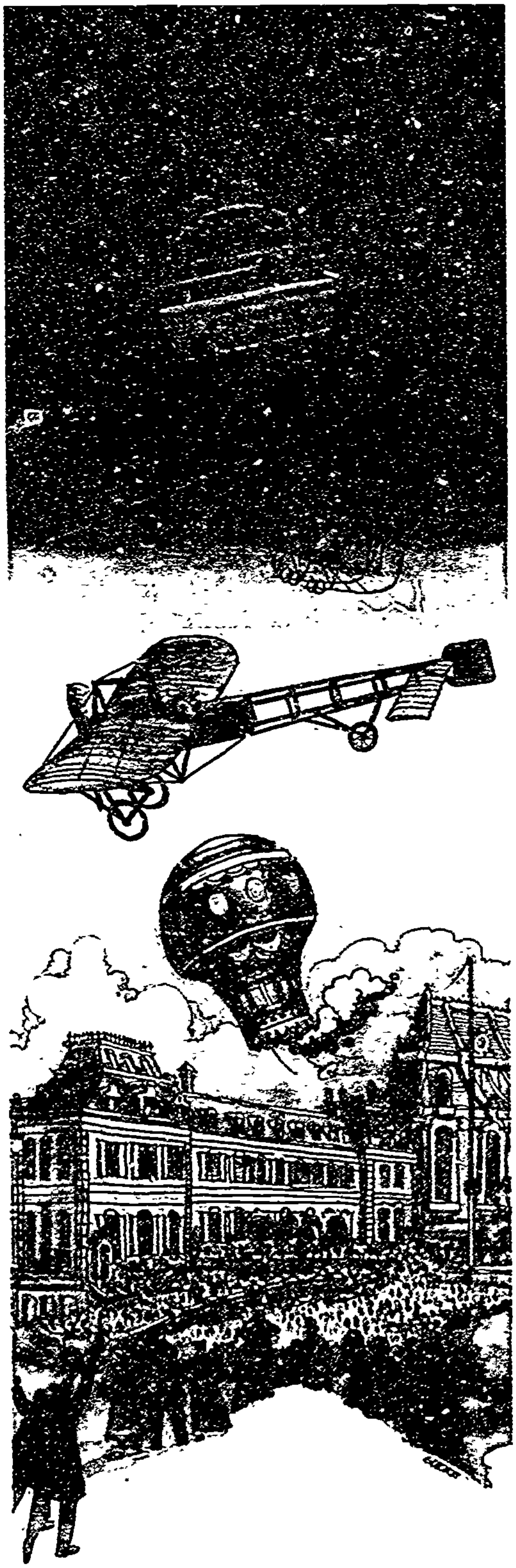


Diagram of the magnetosphere of Venus

The Orbiter travels in an elliptical orbit around the planet. This enables its instruments to sample various regions of the planet's ionosphere (the region of charged particles in the upper atmosphere) which is a thinner ionosphere than that of Earth. Venus has no magnetic field to shield it from the solar wind, but the wind itself generates a magnetic field.

The induced magnetic field deflects the solar wind and gives rise to a bow shock and an ionopause (which has no terrestrial counterpart). The ionopause is the boundary between the ionosphere and the solar wind. The spacecraft showed that the ionopause exists on the night side as well as the day side of the planet and it identified and mapped specific ionospheric regions. an ionosheath, a mantle, and a wake. Changes in the ionosphere and the particles and field environment surrounding Venus were recorded as solar activity, and the strength of the solar wind changed during the solar cycle. A new understanding of how a planet without a magnetic field interacts with the solar wind is being developed, and contributions to the possible explanations for some of the differences between Earth and Venus are being made.

Outer Solar System Pioneers



Scientists gave high priority to extending the exploration of the "outer" space frontiers. Early in the 1970s scientific descriptions of the outer parts of the Solar System still differed enormously because details were lacking from observations made from Earth. There were many unknowns about the far reaches of interplanetary space beyond the orbit of Mars and about the very large and distant planets of the outer Solar System in which most of the matter and the angular momentum of the total system are concentrated.

Between the orbits of Mars and giant Jupiter, the Asteroid Belt was known to contain many thousands of small rocky bodies, nearly all less than a few tens of miles in diameter and possibly including untold numbers of very small particles. There were doubts that spacecraft could safely cross this region. To do so was important to our finding out more about the outer giants, particularly so because to reach the more distant planets requires full use of Earth's orbital velocity around the Sun and a spacecraft trajectory directly through the heart of the asteroid belt. The gravity and orbital motion of Jupiter are then used to urge a spacecraft flying by that planet to the high velocities needed to reach other more distant planets — Saturn, Uranus, and Neptune — within reasonable times and with reasonable scientific payloads.

The first outer-planet target for the Pioneers was Jupiter, giant of the system and almost a protostar, with its retinue of giant satellites. The design challenges for Pioneers 10 and 11 — precursors to later missions by larger spacecraft — were to explore the Jovian system and obtain the first closeup spin-scan images of the planet and to investigate its enormous magnetosphere, the composition of the planet's turbulent atmosphere, and its internal physical structure. Radio signals had been traced as originating from Jupiter, implying that it had a large magnetosphere with intense radiation belts, the spacecraft had to survive this radiation environment.

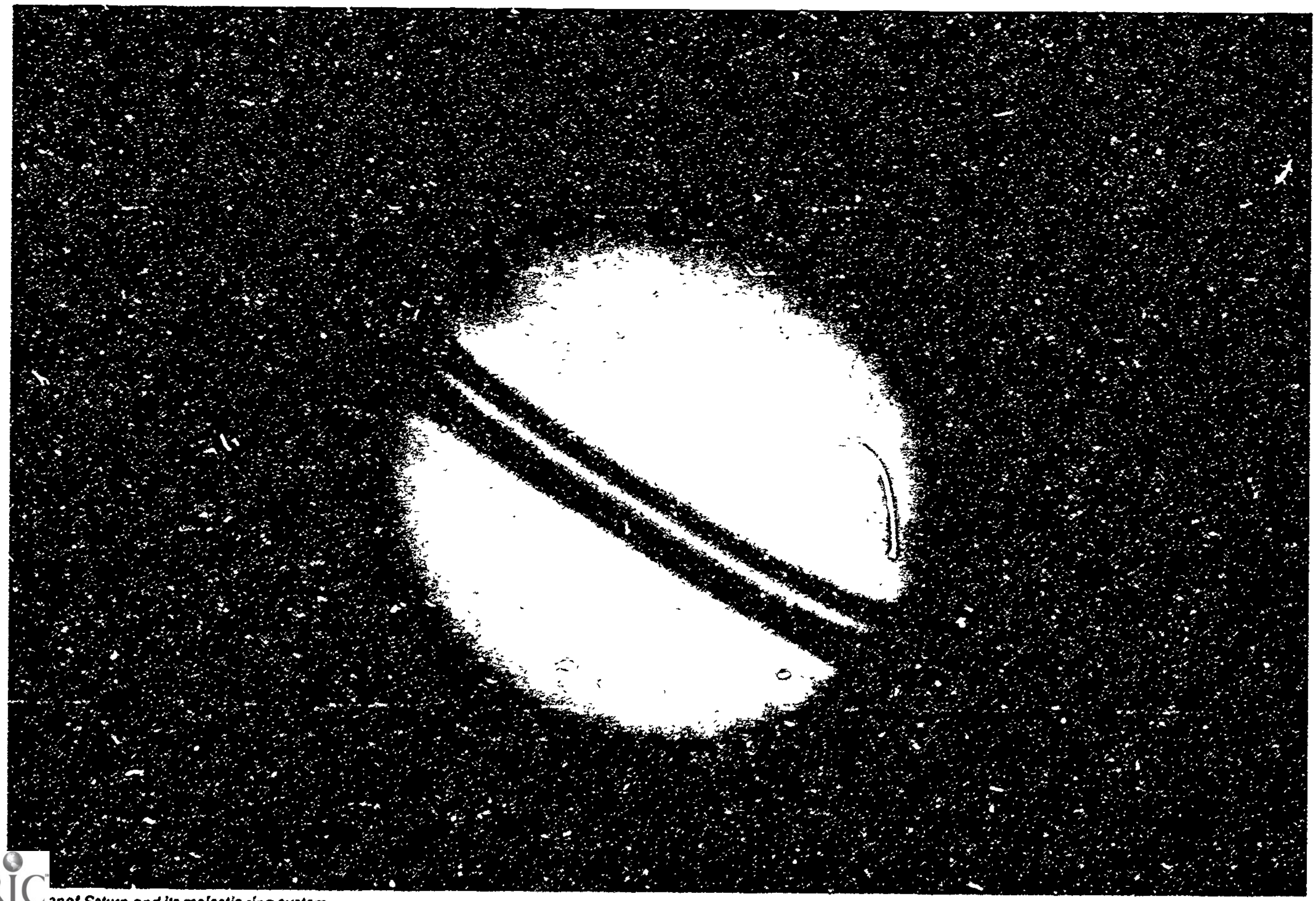
Despite its enormous size, 11 times the diameter of Earth, Jupiter is the most rapidly rotating body in the Solar System. From Earth we see light and dark bands crossing Jupiter's disk, an enormous Red Spot that has been observed for centuries, and rapidly changing weather features. We recognized the presence of hydrogen, helium, water vapor, ammonia, and methane in the planet's atmosphere, and we believed Jupiter to be a gas giant consisting predominantly of hydrogen in gaseous, liquid, and metallic forms.

The successful encounter of Pioneer 10 with Jupiter, and the meeting of all its scientific objectives, permitted Pioneer 11 to be retargeted in flight to fly by Jupiter in such a way that it was hurled on to intercept the majestically ringed planet, Saturn. Pioneer 11's survival attested to the outstanding engineering and operational efforts that had gone into its design. The redirection and acceleration of Pioneer 11 toward Saturn required a tightly curved passage from south to north around Jupiter, enabling that second flyby to penetrate the deepest ever into Jupiter's radiation belt and to provide an unparalleled perspective of the giant planet's polar regions. This retargeting was aimed toward a Saturn flyby that would explore the feasibility of Voyager later making a safe passage by Saturn on its way to Uranus and Neptune.

Saturn, slightly smaller than Jupiter and nearly twice as far from the Sun, is another giant consisting of so much gas that its density is less than that of water. The planet also has a retinue of satellites and an enormous ring system whose dynamics had intrigued mathematicians for centuries. Information about Saturn was even more sketchy than that about Jupiter. It, too, is a rapid rotator. It, too, has belts and spots. But these features are very much less distinct than those of Jupiter. And beyond Saturn is the outer Solar System, stretching billions of miles into space, the realms of Uranus, Neptune, and Pluto, and of the solar wind blowing out toward a boundary referred to as the heliopause where the influence of the Sun ends and a spacecraft traveling fast enough would enter interstellar space and reach for the stars.

The planet Jupiter and its Great Red Spot

Important discoveries were made by Pioneers 10 and 11, discoveries with far-reaching consequences for future space exploration and for our understanding of the Solar System and of vast magnetospheres containing energetic plasmas that we cannot duplicate in laboratories on Earth. First, the myth of a hazardous asteroid belt was dispelled. The anticipated concentration of small particles did not exist. Spacecraft could safely reach Jupiter and use the Jovian gravitational slingshot to hurtle them to more distant planets.



anet Saturn and its majestic ring system

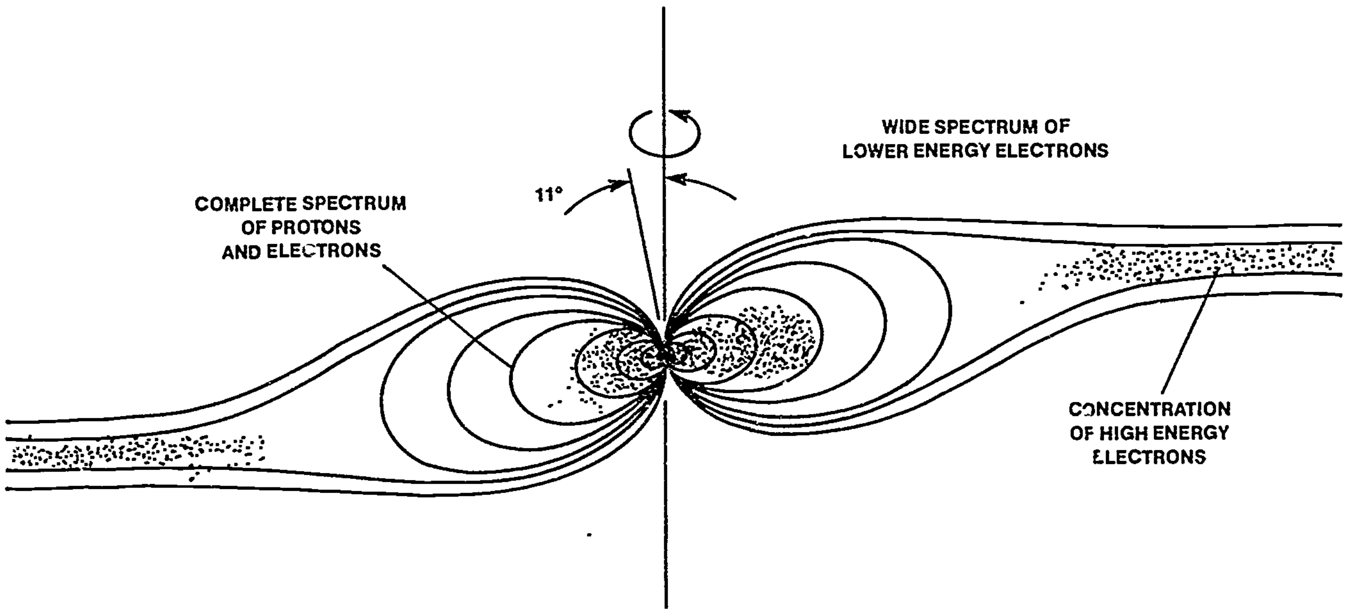


Diagram of the enormous magnetosphere of Jupiter as revealed by the Pioneer 10 and 11 spacecraft

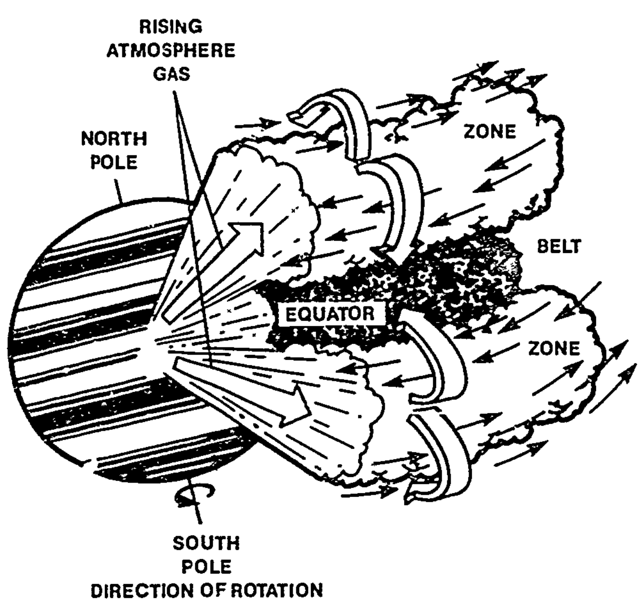


Diagram of the cloud belts and zones of Jupiter

The Pioneers made discoveries about the distribution of particles causing the Zodiacal Light and the Gegenschein, glows in the night sky observed from Earth. They also mapped the background of starlight.

At Jupiter, the Pioneers explored the giant planet's magnetosphere and found that it is disk shaped and bigger than the Sun itself. The magnetic field of Jupiter, 10,000 times stronger than Earth's field, is opposite in direction to Earth's field, its dipole moment is offset and tilted so as to cause a wobbling of the huge magnetosphere as the planet spins on its axis.

The Pioneers discovered a ring current within the magnetosphere and radiation belts whose trapped electrons have an intensity 10,000 times Earth's trapped electrons, and its protons, 1000 times Earth's. Jupiter's magnetosphere was also revealed as the source of high-energy electrons observed everywhere that spacecraft have traveled in the heliosphere.

The ratio of helium to hydrogen in the Jovian atmosphere was found to be 0.14, fairly close to the 0.11 ratio of the Sun. Close-up pictures were obtained of the belts and zones, of the Great Red Spot, and of the polar regions. A new understanding was obtained of the weather patterns on a giant, rapidly rotating planet with no solid surface.

The heat balance was measured and showed that Jupiter emits 1.7 times the heat the planet receives from the Sun, indicating that heat is still being generated in its vast interior.

At Saturn, Pioneer 11 found and explored another magnetosphere and made equally important discoveries. The suspected presence of a magnetic field was confirmed. It has a very small tilt and possesses the same polarity as the Jovian field, with a dipole moment about 540 times that of Earth's field. The magnetosphere contains corotating plasma and radiation belts comparable in intensity to Earth's but much larger in size. Rings and satellites were found to absorb particles and sweep them from the radiation belts.

Close-up pictures obtained of the belts and zones showed them as narrower and more numerous than Jupiter's. Cyclonic spots were also recorded on the images, and high-velocity zonal winds were discovered. The atmosphere has thicker clouds having less contrast than those of Jupiter, presumably because Saturn's atmosphere is colder because of its greater distance from the Sun.

The heat balance was measured as at Jupiter and the measurement showed that Saturn emits 2.8 times the heat it receives from the Sun. One explanation is that helium is gravitationally separating within the atmosphere and the interior of Saturn and is releasing energy as it falls toward a rocky core and solidifies under the intense internal pressure.

The vast ring system was imaged and more details were revealed than can be seen from Earth. The rings were also observed from behind the planet to reveal even more structure when back-lighted. An extremely narrow F ring was discovered, visible outside the outermost ring seen from Earth, and other extremely tenuous rings were detected by their absorption of particles from the magnetosphere. Before making its closest approach to the cloud tops, Pioneer showed that a spacecraft could penetrate the ring plane fairly close to the planet without being damaged. This was an essential precursor to later flybys of Saturn by a larger spacecraft which would be deflected to Uranus.

New small satellites of Saturn were discovered. The imaging photopolarimeter discovered one optically and another was discovered by its distinctive sweeping effects on charged particles. This latter was the first discovery of a satellite by nonoptical means.

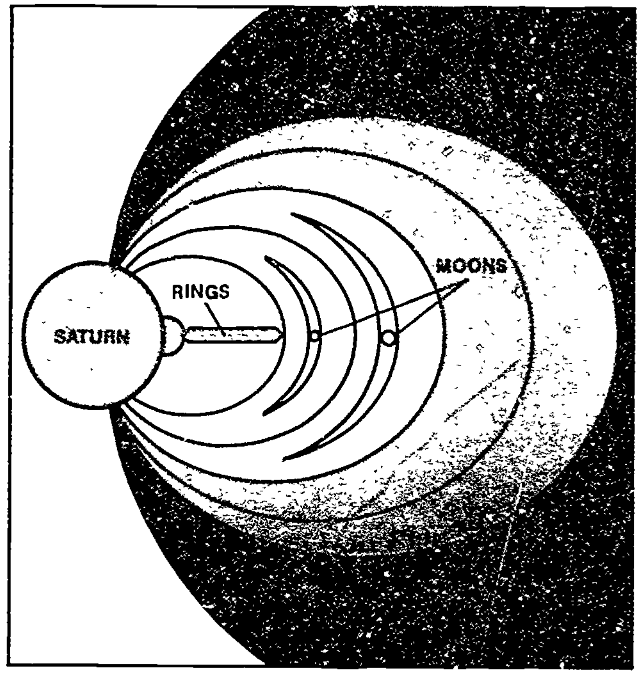
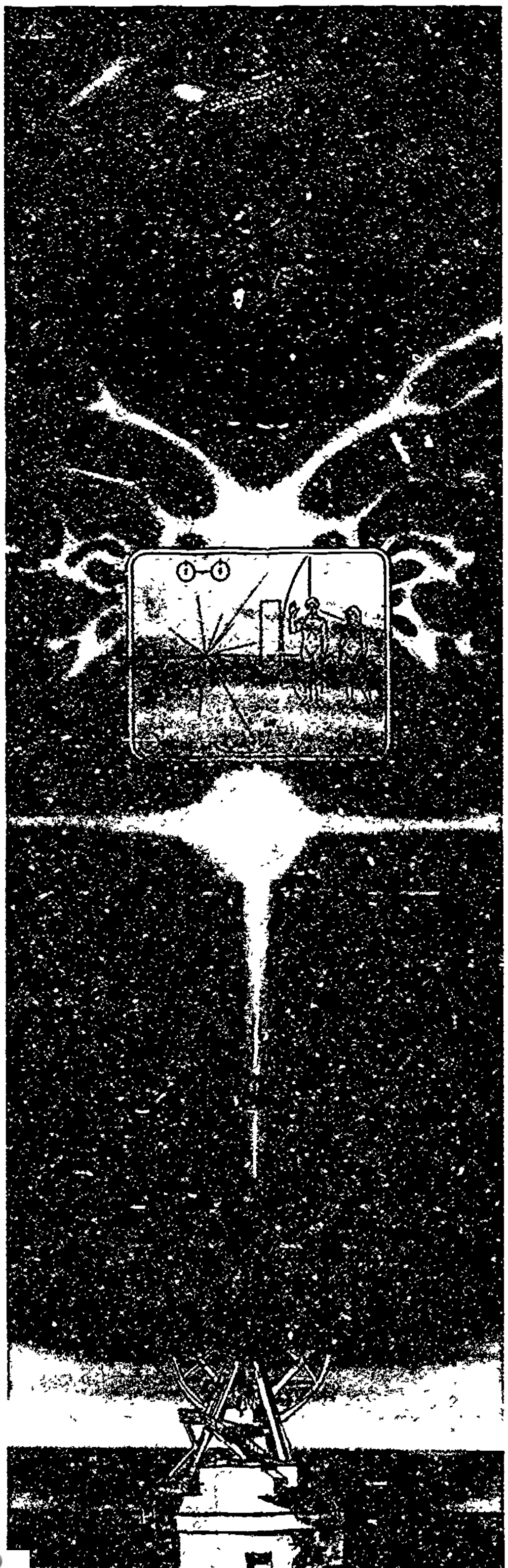


Diagram of the magnetosphere of Saturn discovered by Pioneer 11


...neer spacecraft flies by Saturn

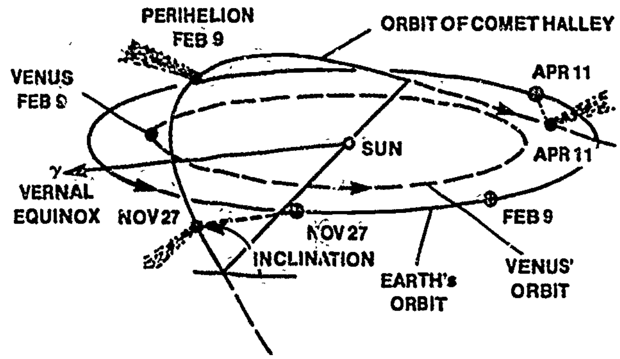
The Pioneers Now And In The Future



At the end of 1986, Pioneers 6, 7, 8, 10, and 11, and Pioneer 12, the Venus Orbiter, are all still operating and gathering data. Pioneer 9's signal was lost in 1983, up to which time, 15 years after launch, it still provided good data. Pioneers 6 and 7 continue to gather solar wind and cosmic ray data inward and outward of Earth's orbit, while Pioneer 8 provides data about electric fields in space. Pioneers 10 and 11, heading out of the Solar System in almost opposite directions, are still pioneering as they explore the remotest regions of the Solar System for the first time in human history. They seek evidence of perturbations from possible remote planets beyond Neptune and Pluto, and from gravity waves originating outside the Solar System. They continue to map the heliosphere, observing the changes and characteristics of the solar wind, and are gradually accumulating data over a complete cycle of solar activity in the far reaches of space.

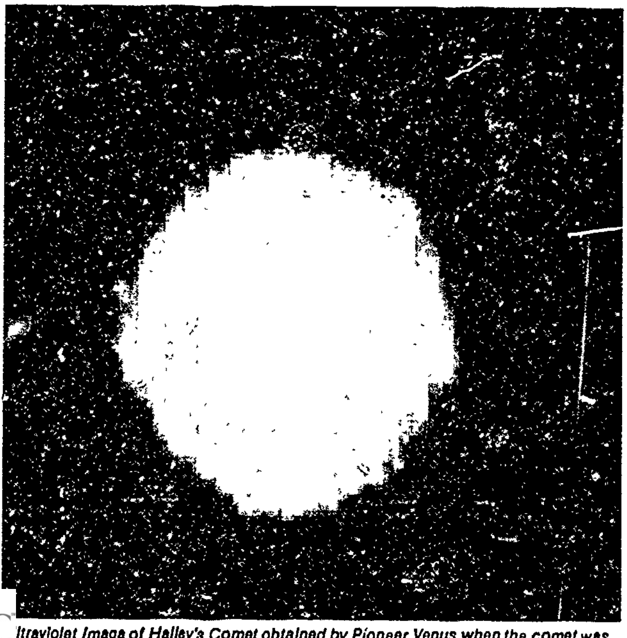
These programs have produced a number of engineering and operational highlights as well as major scientific results. Special encoding of data permitted information to be transmitted over enormous interplanetary distances. Power generators were designed to provide lifetimes very much longer than hitherto achieved. The spacecraft were made magnetically clean so they could measure low-level magnetic fields in space. Entry probes were developed to penetrate the hot, dense atmosphere of Venus and to sample that atmosphere, sending information directly back to Earth. An advanced tracking system arranged around the Pacific basin accurately followed the probes to measure windspeeds in the atmosphere of the distant planet. An antenna despin drive kept an antenna on the spinning Pioneer Venus spacecraft facing Earth for over 8 years without apparant wear. Communications were maintained over many years and great distances with round-trip light time reaching hours for the outer Solar System spacecraft. Scientists and engineers dedicated a decade or more of their professional lives to teams keeping in touch with these long-lived spacecraft.

Pioneer 12 (Pioneer Venus) continues orbiting Venus and accumulating a wealth of information about the planet and nearby space, gathering much information about how the solar wind interacts with a planet lacking an intrinsic magnetic field. In the past 2 years, Pioneer 12 has made significant contributions to the study of comets by its observations of comets Encke, Giacaboni-Zinner, and Halley. It provided entirely new estimates of the rates at which water is released from comet nuclei by solar heating, and spin-scan images of the hydrogen corona of Comet Halley when it was closest to the Sun (i.e., during its perihelion passage). From



Halley's Comet, its path around the Sun in 1985/86 and its close approach to Pioneer Venus

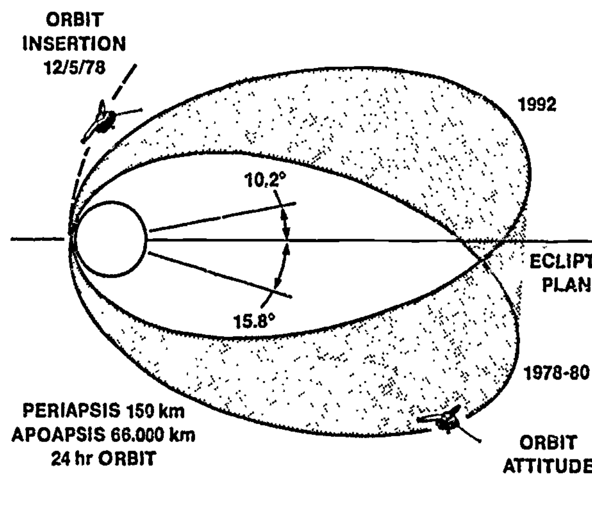
the vantage of Venus' orbit, this Pioneer spacecraft was able to obtain information about comets that could not be obtained from a terrestrial viewpoint; in particular, it provided an opportunity to observe Comet Halley when it was most active. These unique observations of three different comets by one spacecraft benefitted from using the same instrument, an important capability for making comparisons among comets. Pioneer Venus will have the opportunity of observing two comets in 1987. Comet Wilson, a new comet discovered in August 1986, and Comet Encke, one of the most evolved comets known. Both will be observed for many weeks during the comets' most active periods. Together with the observations of Halley, a "middle-aged" comet, these measurements will provide a unique set of comet portraits from youth to old age.



ltraviolet Image of Halley's Comet obtained by Pioneer Venus when the comet was 'ose to perihelion

Comet Halley

The primary scientific objectives of the extended mission of Pioneer Venus are to gain increased coverage in space and time as the orbit around Venus changes. The increased spatial coverage is unique to Pioneer Venus since most planetary spacecraft are locked into one orbit around their target planet. Initially, Pioneer Venus' orbit was held in a controlled configuration but, since the spacecraft completed its low-altitude sampling of the upper atmosphere, the gravity of the Sun is gradually changing the orientation of the orbit and providing additional viewpoints for observing Venus and its near-space environment.



Changing orientation of Pioneer orbiter's path

The nose of the bow shock and the near wake in the cavity behind the planet is where our understanding of the interaction of the solar wind with Venus can best be increased. All regions of this interaction can be investigated during the expected lifetime of Pioneer Venus. This extended mission will provide the first continuous measurement of solar-wind interactions with a planet over a complete cycle of solar activity. Pioneer Venus also describes concentrations of electrons and ions in the ionosphere of Venus, their energy distribution, and their motions over the solar cycle. The changing orbit will permit in-depth studies of the nighttime ionosphere.

Periodic mapping of cloud-top features permits long-term studies of weather patterns on Venus. We can observe the formation and decay of major cloud systems, variations in the haze layers above them, and the changes to the amount of sulfur dioxide in the atmosphere of the planet. A possible volcanic eruption pushing clouds of sulfur dioxide into the atmosphere of Venus just before the arrival of the Pioneer Orbiter there in 1978 has important implications regarding the current state of Venus and whether it is still volcanically active.

From such observations we look forward to gaining a better understanding of the photochemical and aerosol processes occurring at Venus, and how the zonal circulation is generated — and a better understanding of planetary meteorology in general.

Early in 1992, Pioneer Venus will enter a final phase of operations. Exhausted of the propellant needed to offset solar gravitational influence upon the orbital trajectory, the spacecraft will enter the atmosphere of Venus and be destroyed. For a brief period there will be sufficient propellant to keep the spacecraft orbiting almost as it was during the early part of its mission. The important difference will be that the periapsis — the closest approach to Venus in each orbit — will be located in the southern, instead of the northern, hemisphere. The radar can be turned on again to get mapping data about regions closer to the south pole, and confirm data from areas that were distant earlier in the mission. In-situ measurements of the atmosphere can be made at altitudes below 140 kilometers as the periapsis descends lower into the atmosphere. The ionosphere can be sampled in the southern hemisphere. And while the nominal mission in 1978 corresponded with a minimum of solar activity, the reentry phase will be close to a solar maximum.

Information being gathered by Pioneers 10 and 11 can be compared with that gathered by the Voyager spacecraft as they broach the outer regions of the Solar System and in different directions from those of the Pioneers. The magnetic field in the outer Solar System has been found to correspond fairly closely with a spiral field model developed in the late 1950s. The effects of solar maximum and minimum activities are being observed, with a minimum expected in 1987, also, the effects of the recent 22-year cyclical reversal of the solar magnetic field can be studied.

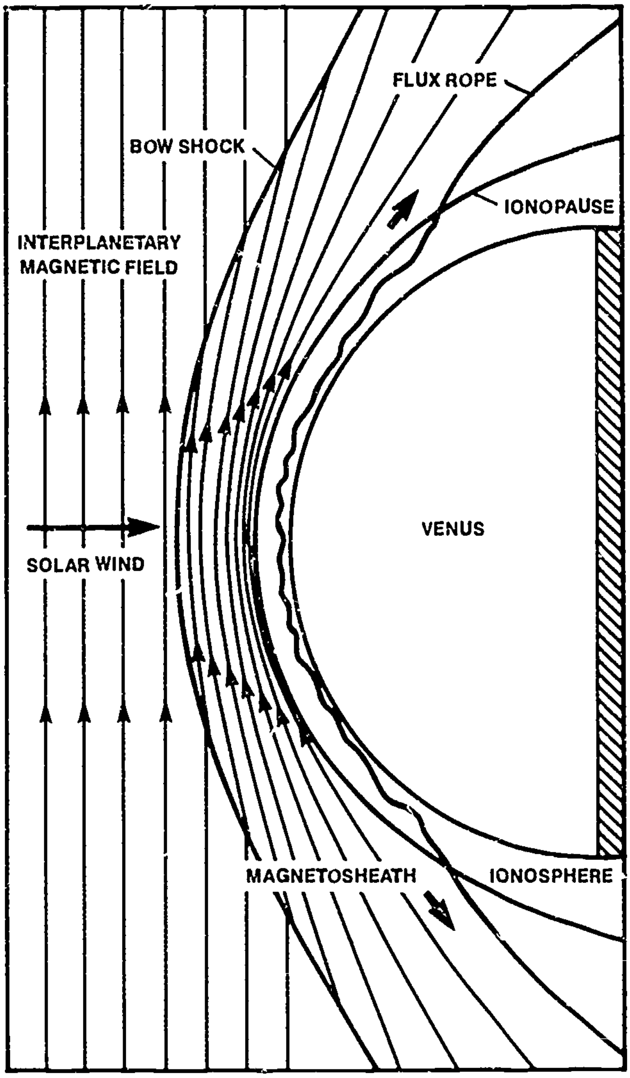
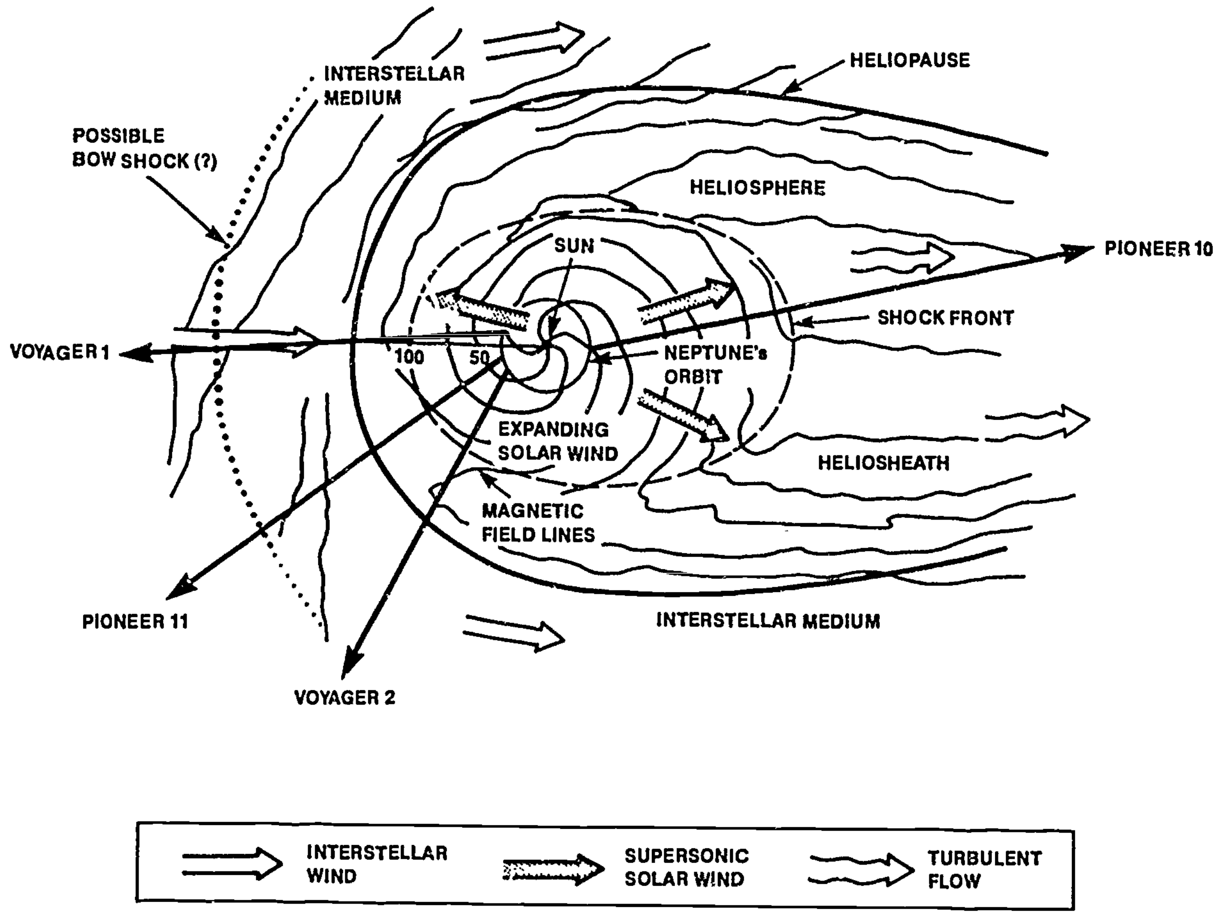


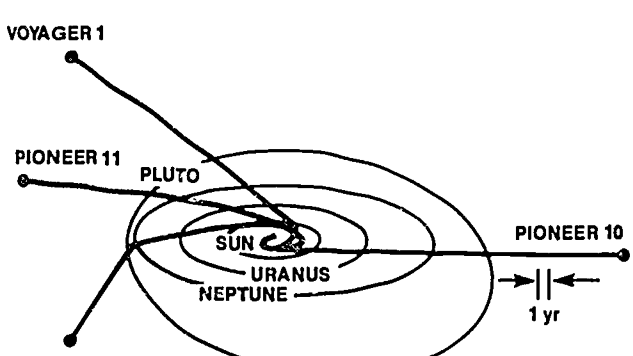
Diagram of interaction of the solar wind with Venus

The magnetometer and charged-particle instrumentation carried by the two spacecraft are recording the distribution of cosmic ray particles and have revealed that low-energy particles are trapped in a corotating structure, a kind of containment bottle. Four experiments are investigating cosmic rays in the heliosphere and how the various types and energies are affected by the solar cycle.

Most cosmic ray particles from the Galaxy are excluded from the Solar System at periods of solar maximum activity, and the anomalous component of the cosmic rays is extremely sensitive to the solar cycle. Recovery of low-energy Galactic cosmic ray particles by the instruments aboard Pioneer began in 1984 as the solar activity declined. It is expected that the region of the heliosphere where modulation of the incoming cosmic rays occurs is at a distance of between 40 and 90 AU. It is highly probable that by 1989 Pioneer 10 will be the first spacecraft to reach the boundary of cosmic ray modulation. The question is whether there will be a clean shock between the heliosphere and interstellar space, or if there will be only a turbulent region. Many of the experiments carried by Pioneer 10 are capable of



Paths of the Pioneer spacecraft through the heliosphere and out of the Solar System



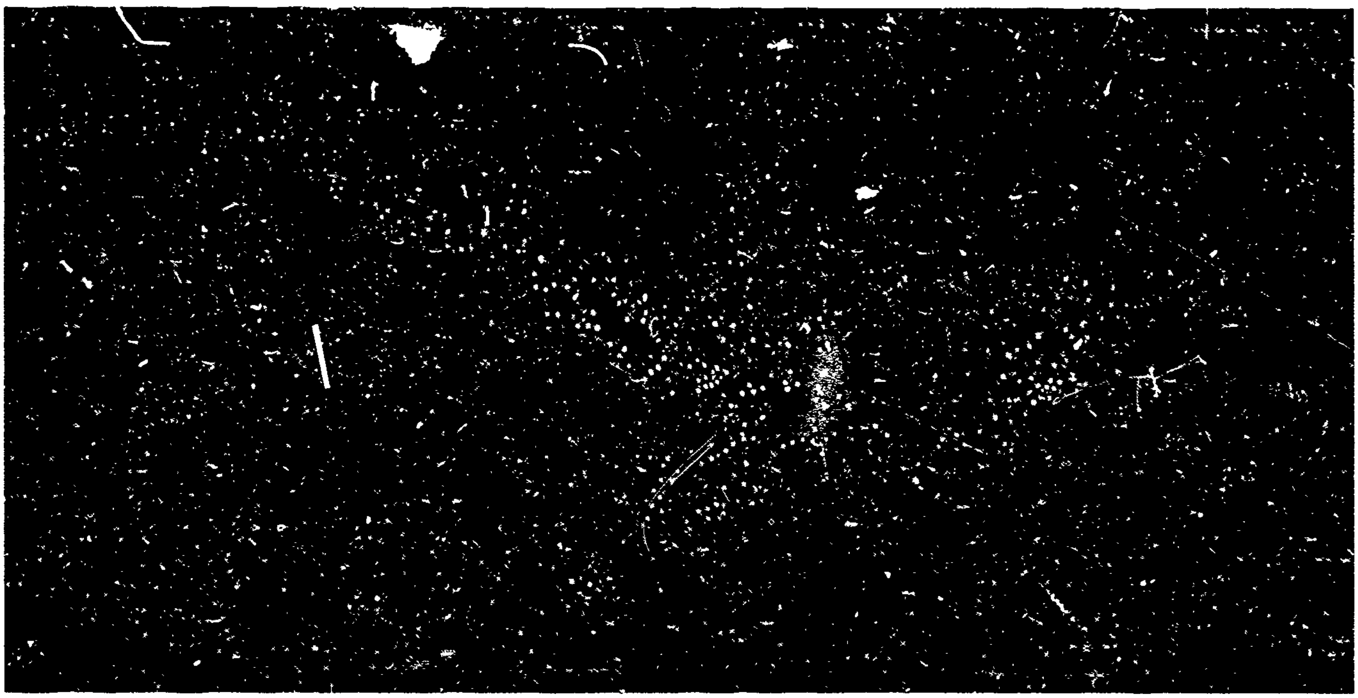
Relative paths of four spacecraft leaving the Solar System for interstellar space

detecting this boundary. Finding out how cosmic rays enter our Solar System from the galaxy and how they are modulated is important to designing experiments to seek anti-protons so as to gain a better understanding of the building blocks of matter and their origins.

The Doppler tracking data as the Pioneers are passing beyond the previously known limits of the Solar System have been used to check for gravity waves and for perturbations that might result from trans-Plutonian planets or from a companion dark star. So far the results are negative, implying that if there is a planet beyond those presently known, or a dark star responsible for dislodging comets and causing periodic extinctions of life from Earth, it must be extremely distant at present, possibly far out along an elliptical orbit While past influences upon the orbital paths of Neptune and Uranus appear to have been real, a companion dark star is ruled out by Pioneer 10 data as being the cause of such perturbations.

The concept of pioneering spacecraft has paid enormous dividends over the three decades of their activities and explorations beyond the Earth. These relatively inexpensive spacecraft have opened up the Solar System to exploration by more complex machines, machines to carry costly experiments that we could not wisely send into space before we knew the nature of the questions to be asked and the nature of the data to be sought. The Pioneers provided the essential precursor missions. Moreover, they have proved over the years the value of relatively simple and highly reliable spacecraft capable of pushing with minimum risk into new and unexplored frontiers. With Pioneer-type missions we prepare the way for further in-depth studies, more detailed exploration, and hopefully increased wisdom concerning how we as a species can harmonize with the processes of nature. In this way we may discover new ways to apply our increased knowledge and understanding of planets, their evolution, and their interactions with the life-supporting Sun to solve current human problems affecting the terrestrial environment and to avoid inadvertent degradation of our future habitation.

We should salute the people, past and present, of the Pioneer team and those who supported them. Their efforts have revealed new perspectives of our Solar System. These modern Pioneers have told us stories of discovery that will continue to stimulate our imagination relative to the new frontiers of space exploration. Their efforts have presented humankind with an intriguing "Pandora's Box" of discoveries, results, and mysteries, whose interpretation will challenge the technical and scientific community and young students for many years to come.



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The Pioneer Spacecraft

Name	Launch Date		Mission	Status
Pioneer 1	11 Oct.	1958	Moon	72,765 mi. altitude only
Pioneer 2	8 Nov.	1958	Moon	963 mi. altitude only
Pioneer 3	6 Dec.	1958	Moon	63,580 mi. altitude only
Pioneer 4	3 Mar.	1959	Moon	37,300 mi. from Moon, entered solar orbit
Pioneer 5	11 Mar.	1960	Solar orbit	Entered solar orbit
Pioneer 6	16 Dec.	1965	Solar orbit	Still operating
Pioneer 7	17 Aug.	1966	Solar orbit	Still operating
Pioneer 8	13 Dec.	1967	Solar orbit	Still operating
Pioneer 9	8 Nov.	1968	Solar orbit	Signal lost in 1983
Pioneer E	7 Aug.	1969	Solar orbit	Launch failure
Pioneer 10	2 Mar.	1972	Jupiter	Still operating in outer Solar System
Pioneer 11	5 Apr.	1973	Jupiter	Continued to Saturn and still operating in outer Solar System
Pioneer 12	20 May	1978	Venus	Still operating in orbit around Venus
Pioneer 13	8 Aug.	1978	Venus	Successful entry of four probes and bus into atmosphere of Venus

Pioneer Firsts

First U.S. spacecraft to pass the Moon and enter solar orbit (Pioneer 4)

First spacecraft to travel through the asteroid belt (Pioneer 11)

First spacecraft to measure integrated starlight from the Galaxy free of Zodiacal Light (Pioneer 10)

Discovery that the Gegenschein is not associated with Earth (Pioneer 10)

First spacecraft to fly by Jupiter (Pioneer 10) and Saturn (Pioneer 11)

First spacecraft images of the large Jovian satellites (Pioneer 10)

Discovery of an ionosphere on Jupiter's satellite Io (Pioneer 10)

Discovery of a hydrogen torus surrounding Jupiter (Pioneer 10)

Discovery that Saturn's rings and satellites sweep particles from the magnetosphere (Pioneer 11)

Discovery of additional rings and satellites of Saturn (Pioneer 11)

First observation of back-lighted rings of Saturn (Pioneer 11)

Discovery of particles in the ring gaps seen from Earth (Pioneer 11)

First image showing the featureless atmosphere of Titan, Saturn's largest satellite (Pioneer 11)

First polarization measurement of Titan's atmosphere over a wide range of phase angles (Pioneer 11)

First mapping of outer planet magnetospheres (Pioneer 10, Pioneer 11)

Discovery of Saturn's magnetic field and magnetosphere (Pioneer 11)

Mapping of corotating streams of particles from the Sun into the outer Solar System and identification of interplanetary acceleration processes (Pioneer 10 and Pioneer 11)

Mapping of the tightly wound solar magnetic field and discovery of a warped current sheet (Pioneer 10 and Pioneer 11)

First detection of helium atoms entering Solar System from the Galaxy (Pioneer 10 and Pioneer 11)

First spacecraft to leave the known Solar System (Pioneer 10)

First spacecraft to carry messages to extraterrestrials (Pioneer 10 and Pioneer 11)

First simultaneous multiprobe entries of Venus' atmosphere (Pioneer 13)

First topographic maps of cloud-shrouded Venus identifying continental masses, high and low points, and general shape of the planet (Pioneer 12)

First synoptic observations of cloud patterns on Venus over a Venus year (Pioneer 12)

Discovery of polar collar and polar dipole feature on Venus (Pioneer 12)

Observations of solar wind interactions with Venus over a complete solar cycle (Pioneer 12)

First spacecraft observations of comet near perihelion (Pioneer 12)

First observations of three comets by one spacecraft (Pioneer 12)

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