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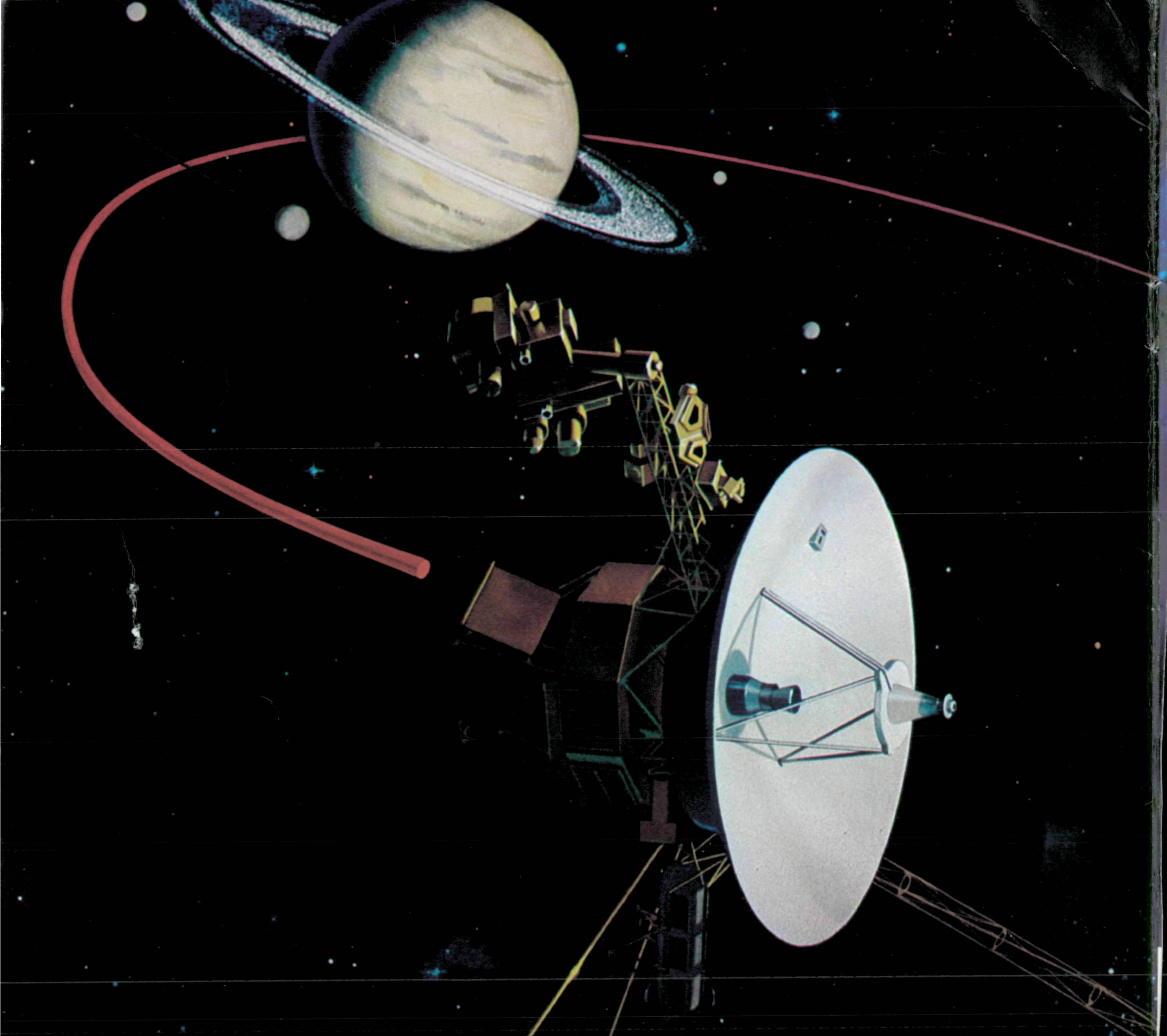
Voyager –

Journey to the Outer Planets

NASA
National Aeronautics and Space Administration

Jet Propulsion Laboratory
Pasadena, California



Introduction

When Galileo Galilei looked through his first primitive telescope in 1610, the surprise that greeted him – four hitherto unknown moons orbiting Jupiter – rocked the world and started a new revolution in scientific inquiry that continues today.

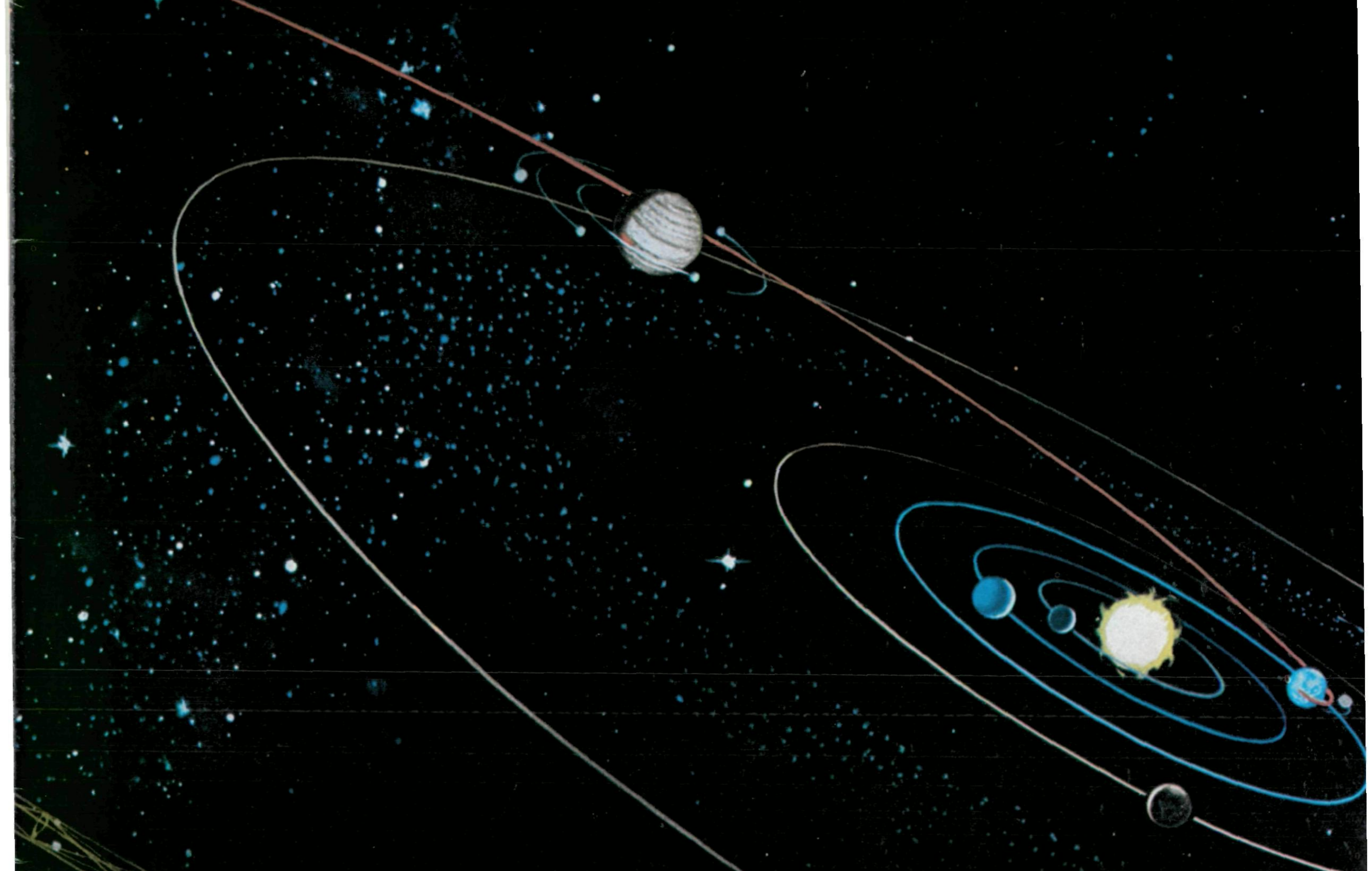
Men had wondered for millenia about the stars that lit the night sky. They puzzled over a few objects, pinpoints of light that didn't obey the rules, that meandered among the fixed stars, refusing to settle down in regular orbits. Men named them "planets" or "wanderers." Violent arguments – even inquisitions – raged over the question, what were these wandering stars?

But each new century found men taking small, painful steps along the road called technology. New instruments were invented, first to measure the positions of the wanderers; then, at last, to magnify their images. Man realized the wanderers were other worlds, perhaps like his own.

Once man learned to break free of Earth's gravity and the murky atmosphere that clouded his vision, he reached out to those wandering worlds. He photographed them from close range, studied their atmospheres and surface markings and chemistry, probed beneath their skins so he might understand what went on deep within.

As he explored, man came to understand that those other worlds relate to his home planet. They provided clues to Earth's origin and distant history, clues to how man might manage his home planet in the future.

Now one of the most exciting of those voyages to other planets — by two advanced Mariner-class spacecraft — the Voyager Project — will examine Galileo's Jovian moons in ways he couldn't have dreamed possible and will observe mighty Jupiter from close range. Then, they will probe even farther to study yet another object that Galileo wondered about — the ringed planet Saturn and its satellites.



Jupiter is so large that scientists sometimes regard the solar system as a two-body group — the Sun and Jupiter. Jupiter's massive gravitational attraction tugs at every other planet and wrenches comets from their orbits. Jupiter resembles a "mini-solar system," with its four "Galilean" satellites, each varying in physical characteristics much as planets vary with distance from the Sun.

Saturn is unique in the solar system: its density is the lowest of the planets, less than that of water; until recently, it was believed to be the only planet encircled by a system of rings — presumably the remnants from the formation of its satellite system. These rings make Saturn a never-ending source of wonder and delight to telescopic viewers.

Four of Jupiter's satellites and one of Saturn's resemble the four inner planets in size and are of such scientific interest that they are worthy of detailed exploration on their own merits.

Dawn of the Mission

As early as August 20, 1977, soon after the Sun blazes out of the Atlantic Ocean off Florida's space coast, man-made fire and thunder will rattle the palmetto scrub as the first of two Voyager spacecraft rides its Titan-Centaur launch vehicle on the first leg of a long journey to Jupiter, Saturn, and beyond, a voyage to the outer planets.

The National Aeronautics and Space Administration will send the two spacecraft to advance our knowledge of the outer solar system – Jupiter, Saturn, their satellites, and perhaps even the farther reaches of space.

The spacecraft will be launched in the late summer of 1977, and will fly past Jupiter in 1979. Using the big planet's immense gravity to boost them on their way, the Voyagers will be accelerated toward Saturn, reaching the ringed planet in 1980 and 1981. There is also the possibility that one of the spacecraft will visit Uranus in 1986.

And then what, beyond Saturn? Both spacecraft will continue farther from the Sun, probing, studying and searching as they go. Far from Earth they will penetrate into galactic space, beyond the influence of the Sun, where they will cruise for eternity.

The Mission Plan

Twelve days after the first launch, the early morning scenario will be repeated. This Voyager, however, will spring after its earlier companion until it overtakes and passes it. This second-launched craft, Voyager 1, will arrive at Jupiter four months before its mate, and at Saturn will be nine months ahead. The slower, first-launched craft, Voyager 2, may be targeted on past Saturn to explore Uranus, if its predecessor Voyager 1 has performed well.

Following in the footsteps of the earlier reconnaissance of the Pioneer 10 and 11 missions, each Voyager spacecraft will conduct 11 separate science investigations, performing for their human masters a thorough physical examination of two planets, at least 11 satellites, the rings of Saturn, and interplanetary space.

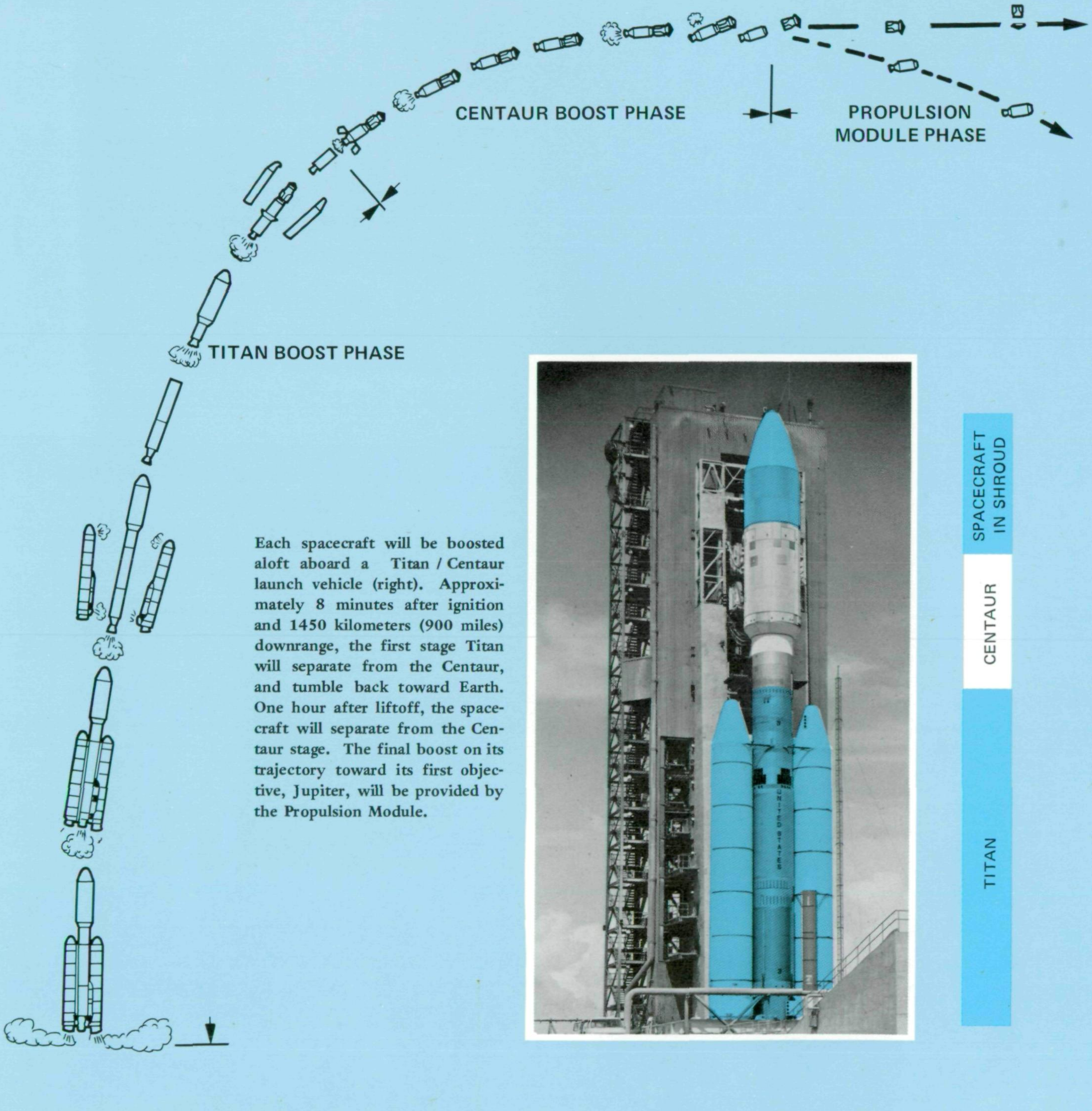
The Voyagers will begin their scientific studies soon after launch. Both spacecraft will aim their instruments back toward the rapidly diminishing Earth; Voyager 1 may pass over the Moon's north pole and get a quick glimpse of our own recently visited satellite.

As mariners have done over the centuries since they took to the sea, these newest will sample the wind – this time the solar wind that streams a supersonic gale of charged particles from the Sun. Instruments will sample the solar wind constantly and about every 50 million miles, each Voyager will spin slowly to scan the sky in all directions.

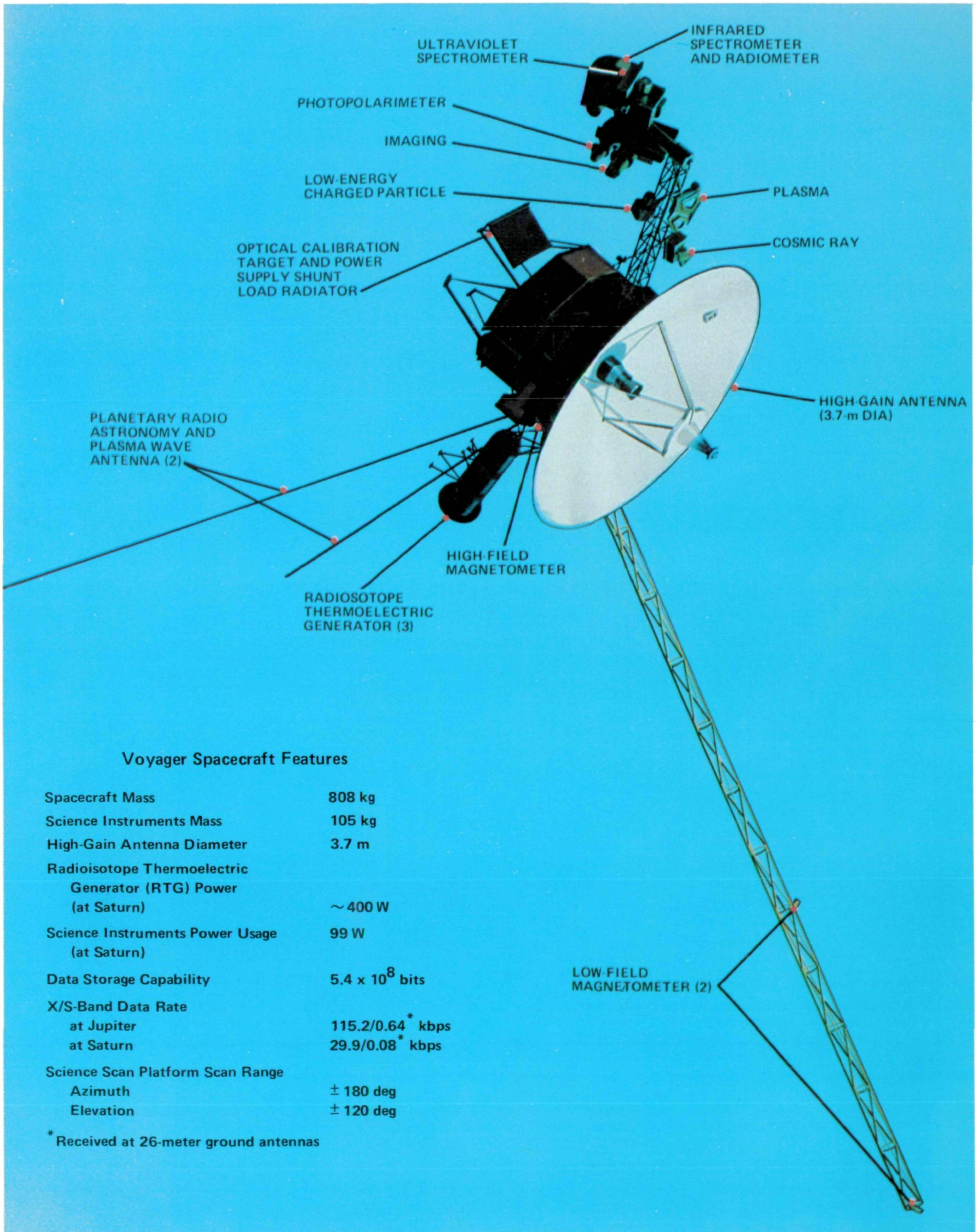
And, like sailors, the Voyagers will thread their way past interplanetary reefs and shoals, as they cross the asteroid belt, a wide band of rock and space debris between the orbits of Mars and Jupiter.

Each Voyager will pursue its own unique trajectory. Flight planners ran computer simulations for many possible flight paths to determine those that would return the maximum possible knowledge — a closer look than the collective efforts of centuries. Both Voyagers will fly past the equatorial regions of Jupiter, and one will pass beneath the south pole of Saturn.

An option exists: if everything has gone well at Saturn and the second spacecraft is still healthy, the slower Voyager 2 may fly on to Uranus, a planet only discovered in 1781 and never visited by spacecraft.



Each spacecraft will be boosted aloft aboard a Titan / Centaur launch vehicle (right). Approximately 8 minutes after ignition and 1450 kilometers (900 miles) downrange, the first stage Titan will separate from the Centaur, and tumble back toward Earth. One hour after liftoff, the spacecraft will separate from the Centaur stage. The final boost on its trajectory toward its first objective, Jupiter, will be provided by the Propulsion Module.



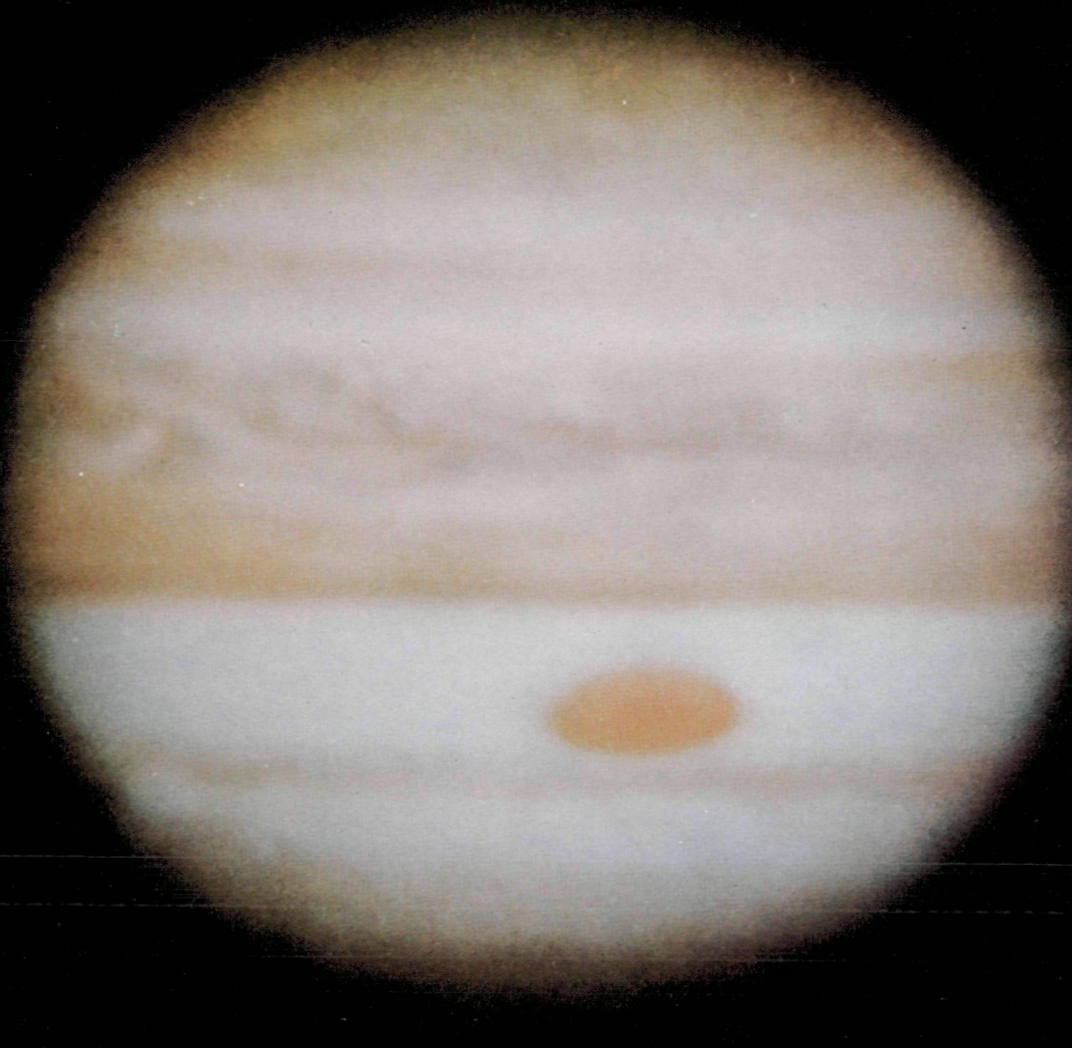
Voyager Spacecraft Features

Spacecraft Mass	808 kg
Science Instruments Mass	105 kg
High-Gain Antenna Diameter	3.7 m
Radioisotope Thermoelectric Generator (RTG) Power (at Saturn)	~400 W
Science Instruments Power Usage (at Saturn)	99 W
Data Storage Capability	5.4×10^8 bits
X/S-Band Data Rate	
at Jupiter	115.2/0.64* kbps
at Saturn	29.9/0.08* kbps
Science Scan Platform Scan Range	
Azimuth	± 180 deg
Elevation	± 120 deg

*Received at 26-meter ground antennas

Eight Months in the Jovian System

More than 16 months after launch – about December 15, 1978 – the speedier Voyager 1 will be transmitting photos of the brilliantly colored disk of Jupiter which



will match the best resolution now available with Earth-based cameras. At this point, eighty million kilometers from Jupiter, Voyager 1 will swivel its scan platform to allow the narrow-angle television camera to begin its "observatory phase," 80 days before closest approach.

The narrow-angle camera will take hundreds of color pictures of Jupiter's visible disk, of the bright red and yellow bands, and of boiling storms like the Great Red Spot, as the planet revolves before the camera once each ten hours. The pictures will be recorded on Voyager 1's tape recorder and played back to Earth daily, across distances so great that the radio signals will travel at the speed of light for more than 40 minutes to reach scientists at th Jet Propulsion Laboratory in California.

Ultraviolet, infrared and polarimetric observations o Jupiter's visible disk will shed more ligh on the planet's unusual structur and composition. The radi astronomy experiment will sense th presence of Jupiter and the radio bursts that appear t emit as much energy as several nuclear bombs. Charged particle sensors – from the plasma detector at the low en of the energy spectrum to the cosmic ray counter at th high-energy end – should still be observing solar-win phenomena although there will be occasional bursts o energetic particles from Jupiter.

Voyager 1 will cruise on, drawing ever nearer it growing target, until in early February 1979, it will b 30 million kilometers distant with 30 days to go befor encounter (closest approach). By now Jupiter will loo two and a half times larger in Voyager 1's eyes than it appeared in December. All activities will sharply increase; scientists will begin to select atmospheric features of special interest, such as the Great Red Spot and other storms for close-up observation nearer the planet. Jupiter's satellites will begin to come within reach of the spacecraft's television eyes now. There are 13 or 14 known Jovian satellites; of these, four are comparable in size to our Moon and two of these are larger than Mercury; at least another four orbit Jupiter "in the wrong direction," in what astronomers call retrograde orbits. One of the biggest satellites, Io, has an effect on those great Jovian radio bursts which Voyager will listen to and report on.

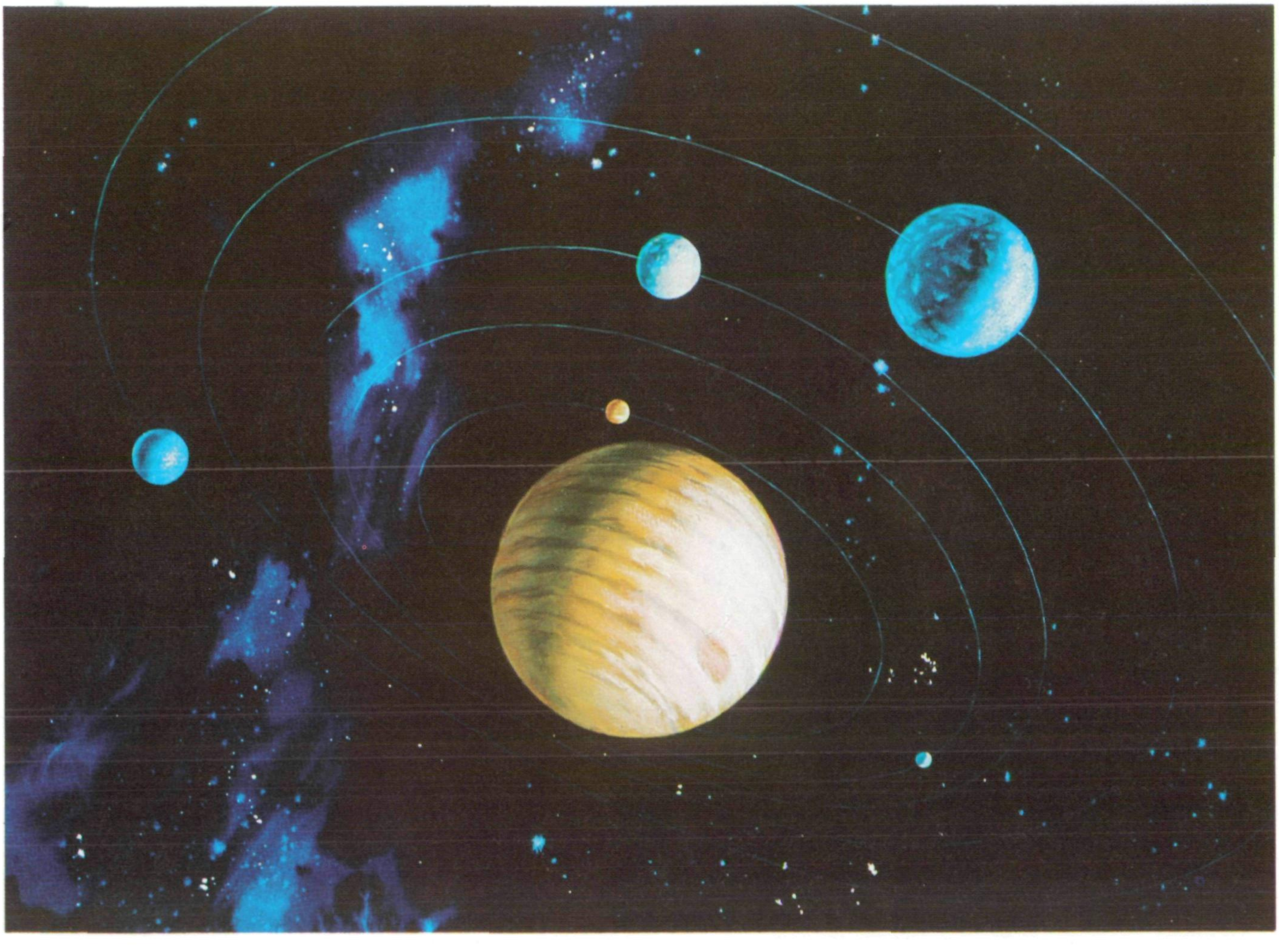
Still the planetary voyager will sail on. Eight days before closest approach, Jupiter will be so near that the narrow-angle camera can no longer effectively cover the entire disk; the wide-angle camera will assume that chore while the other instrument looks at selected phenomena. Spectrometers will scan the atmosphere and the cloud tops to help determine the composition and nature of the brilliant cloud bands.

1979: The First Encounter

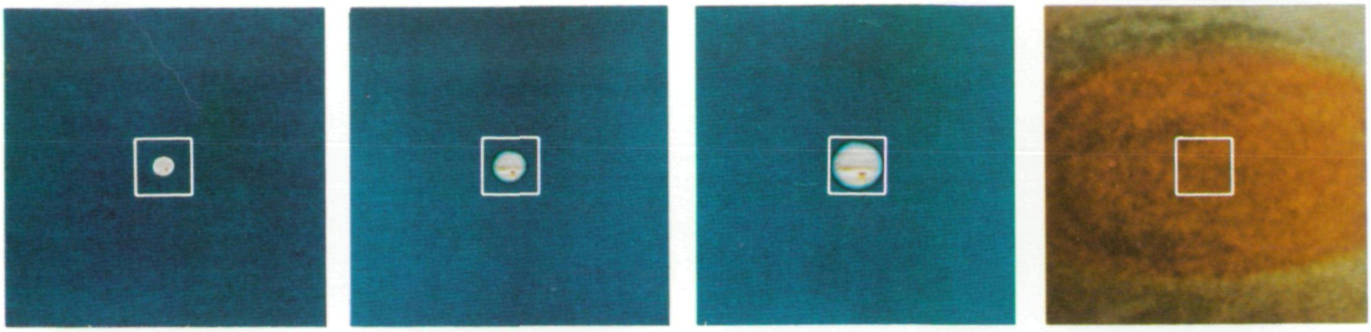
Near-encounter will occur during the first days of March 1979. By now, high-energy radiation in Jupiter's magnetosphere will be bombarding the spacecraft and its intricate electronics.

Activity on board the Voyager and back at Earth will reach a peak. Shortly before Voyager 1's closest approach to Jupiter – early on March 5, 1979 – the spacecraft will pass tiny Amalthea, innermost of Jupiter's satellites, and will photograph it from a distance of 415,000 kilometers. The pictures that flash toward Earth will give scientists their first-ever close look at Amalthea.

Voyager 1 will whip by Jupiter about 280,000 kilometers (a distance equal to 4 Jupiter radii) from the visible surface of the planet. Now the radiation bombardment will reach its peak, but Voyager 1 will bore ahead. Then . . . nothing. No word from the Voyager for almost two hours as it slips behind Jupiter. Its computers will direct the flight, the data collection by its instruments, and

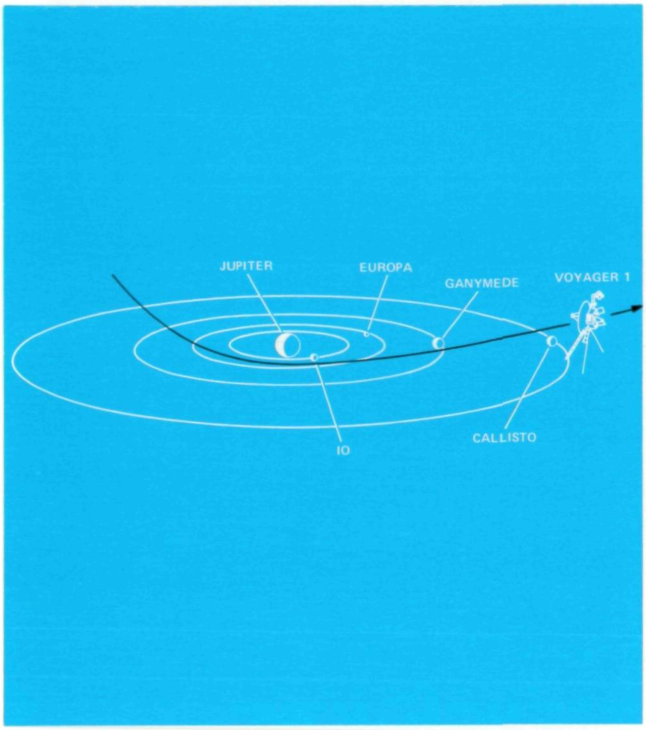


Voyager will scrutinize the giant planet Jupiter and five of its 13 or 14 known satellites.

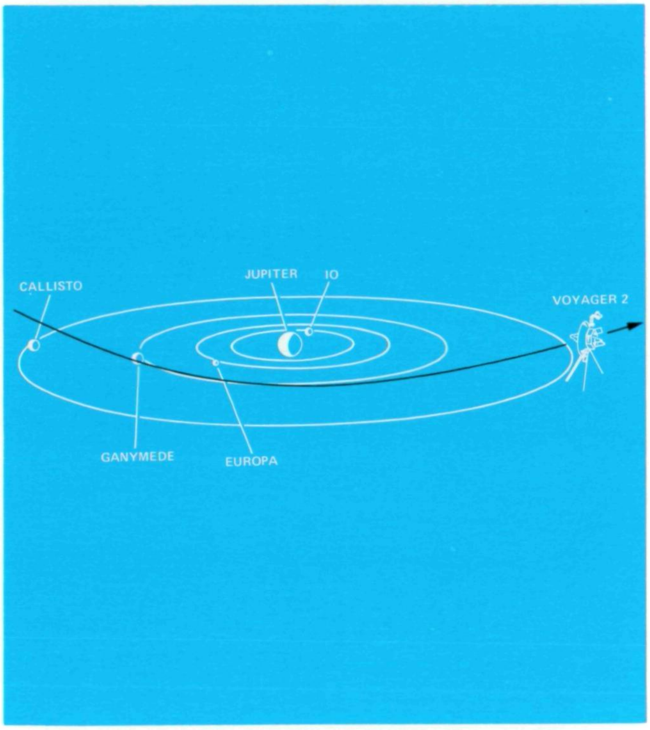


December 1978 Encounter - 80 days	February 1979 Encounter - 29 days	February 1979 Encounter - 18 days	March 1979 Encounter - 7 hours

In December 1978, eighty days before closest approach, Jupiter will be a mere speck in the eye of Voyager's wide-angle cameras. But with each passing day, it will grow until it overflows the cameras' fields of view as the spacecraft nears its closest approach point in early March 1979. The white squares indicate the field of view of the narrow angle cameras.



Voyager 1's closest approach to Jupiter will be about 280,000 kilometers from the visible surface, as it passes between the great planet and its nearest satellite, Amalthea (hidden behind the planet in this simulated view). Closest approach to each satellite will occur as Voyager 1 passes out of the Jovian system.



Voyager 2, on a more cautious trajectory to avoid the intense planetary radiation, will pass 645,000 kilometers from Jupiter at its closest point. This flight path will cause Voyager 2 to encounter the satellites before the planet itself, as seen in this simulated view showing closest approach to each satellite.

the recording for later playback to Earth. As Voyager 1 disappears behind Jupiter, scientists will obtain valuable measurements of the atmosphere of the planet as sunlight and the dual-frequency (S-band and X-band) radio links pass through and are affected by the atmosphere.

As Voyager 1 soars away from Jupiter, boosted into its new flight path toward Saturn, it will examine all four of the big Galilean satellites of Jupiter: Io from 22,000 kilometers at +3 hours after closest approach, Europa from 733,000 kilometers at +5 hours, and Ganymede and Callisto from 120,000 kilometers at +14 hours and +29 hours, respectively.

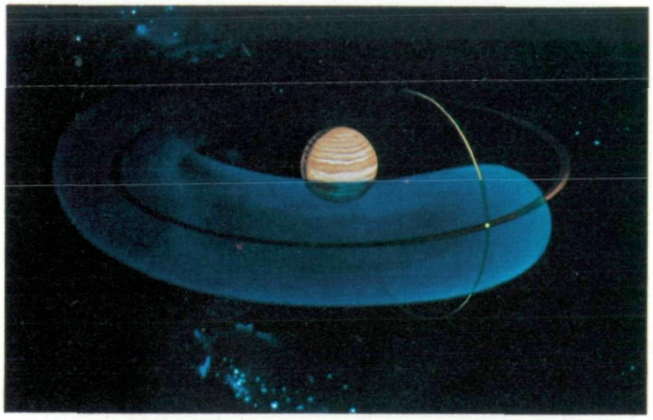
Jupiter, and perhaps all of the outer planets, has an extensive magnetosphere, a region surrounding the planet in which energetic particles are trapped by the planetary magnetic field. The outer, least dense region of the Jovian magnetosphere is highly variable in size, perhaps due to varying pressure of the impinging solar wind.

As Voyager 1 brushes past Io, it will pass through the "flux tube," a region of magnetic and plasma interaction between Jupiter and Io caused by the intersection of Jupiter's magnetic field with Io. This tube, believed to be a circular cylinder of about the diameter of Io, affects the Earth-reception of Jupiter's radio emissions, and is a region of magnetic and plasma interaction.

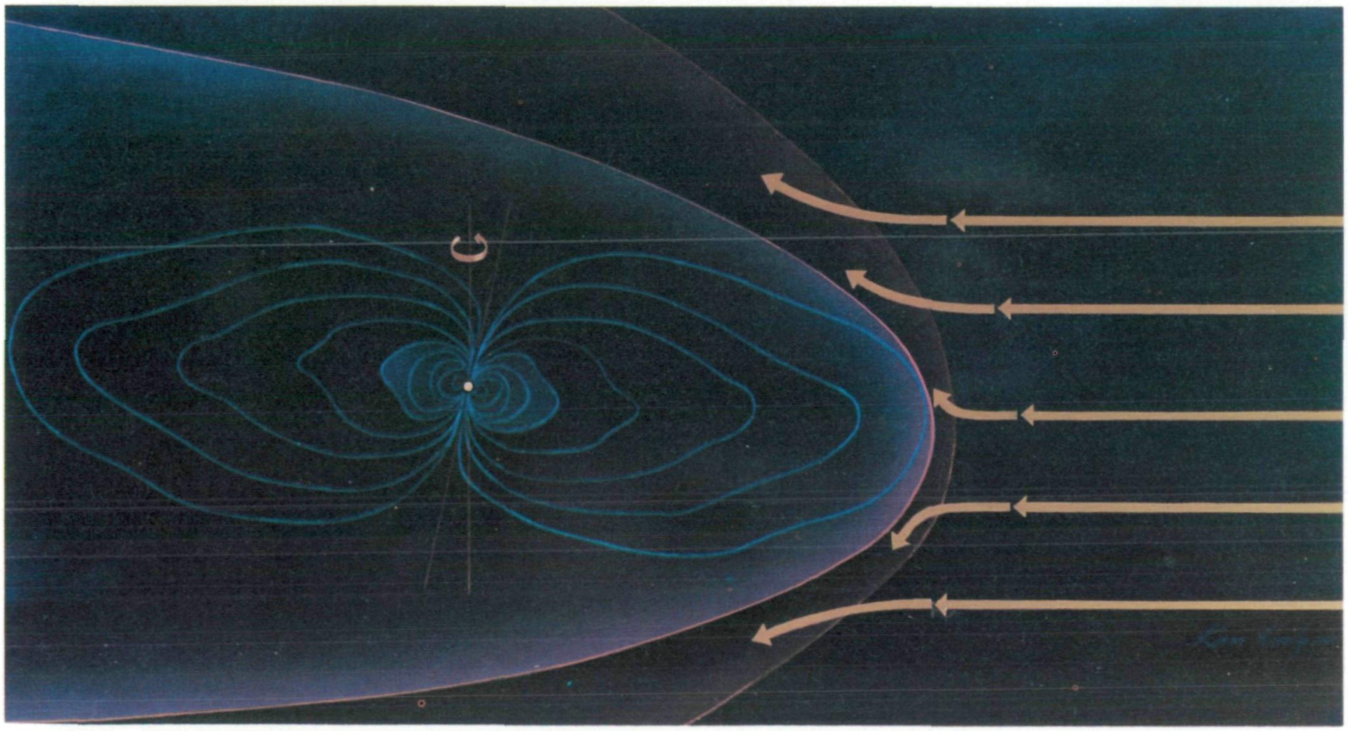
Jupiter's gravity will slingshot Voyager 1 toward Saturn, 800 million kilometers farther from the Sun. As Jupiter grows smaller and smaller in the instruments' fields of view, Voyager 1 will continue to examine the planet and its satellites until mid-April, about six weeks after closest approach.

The second craft, Voyager 2, sailing along behind its speedier companion, will now move within range of Jupiter. Its "observatory phase," similar to Voyager 1's, will begin about April 20, 1979 and will last for approximately five weeks. Voyager 2 will continue the long-term observations, making what amounts to a motion picture of atmospheric movement of the largest planet in the solar system.

Voyager 2 will navigate a more cautious course: to avoid much of the intense radiation near the planet, it will fly much farther from Jupiter than its predecessor – no closer than 645,000 kilometers (about 9 Jupiter radii). It will not repeat the close flyby of Io, but before Jupiter encounter it will survey Callisto from 220,000 kilometers and Ganymede from 55,000 kilometers. It will fly within 201,000 kilometers of Europa and will take a flashing glance at Amalthea from 550,000 kilometers. Voyager 2 will make its closest approach to Jupiter on July 9, 1979. As it heads on towards Saturn, the craft will spend the rest of July and early August looking back over its shoulder at the receding Jupiter.



Between Jupiter and its satellite Io, Voyager 1 will pass through the flux tube (yellow), a region of high magnetic and plasma interaction. Jupiter is encircled by a cloud of hydrogen, while clouds of hydrogen (blue) and sodium (orange) surround Io, and trail the satellite's orbital path.



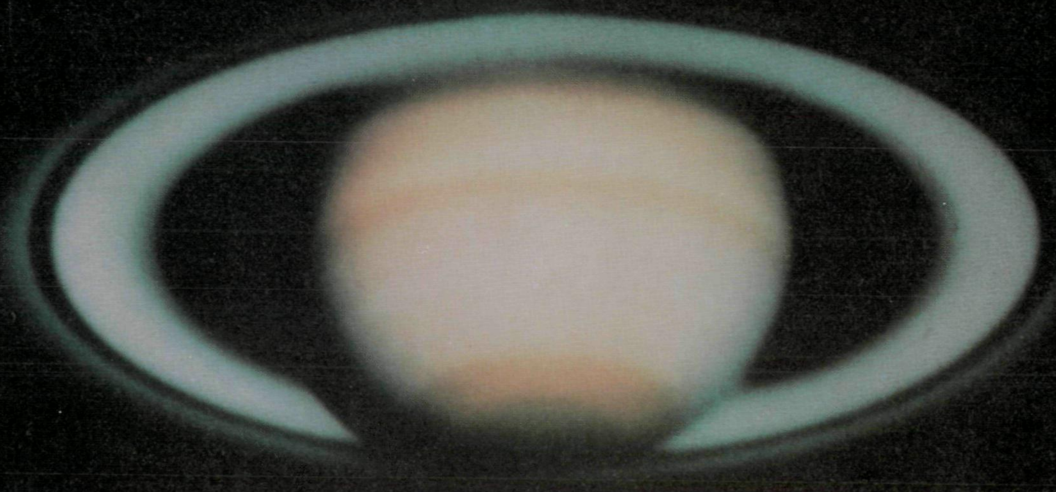
The outer, least dense region of the Jovian magnetosphere is highly variable in size, perhaps due to varying pressure of the impinging solar wind.

Exploring Saturn

Both craft will fly on through space, making their measurements and observations of a variety of phenomena and radioing their findings back to Earth. About one year after the Jupiter mission has ended, Voyager 1 will begin studying Saturn, in August 1980. By now the speedier Voyager 1 will have gained nine months on its lagging sister-spacecraft.

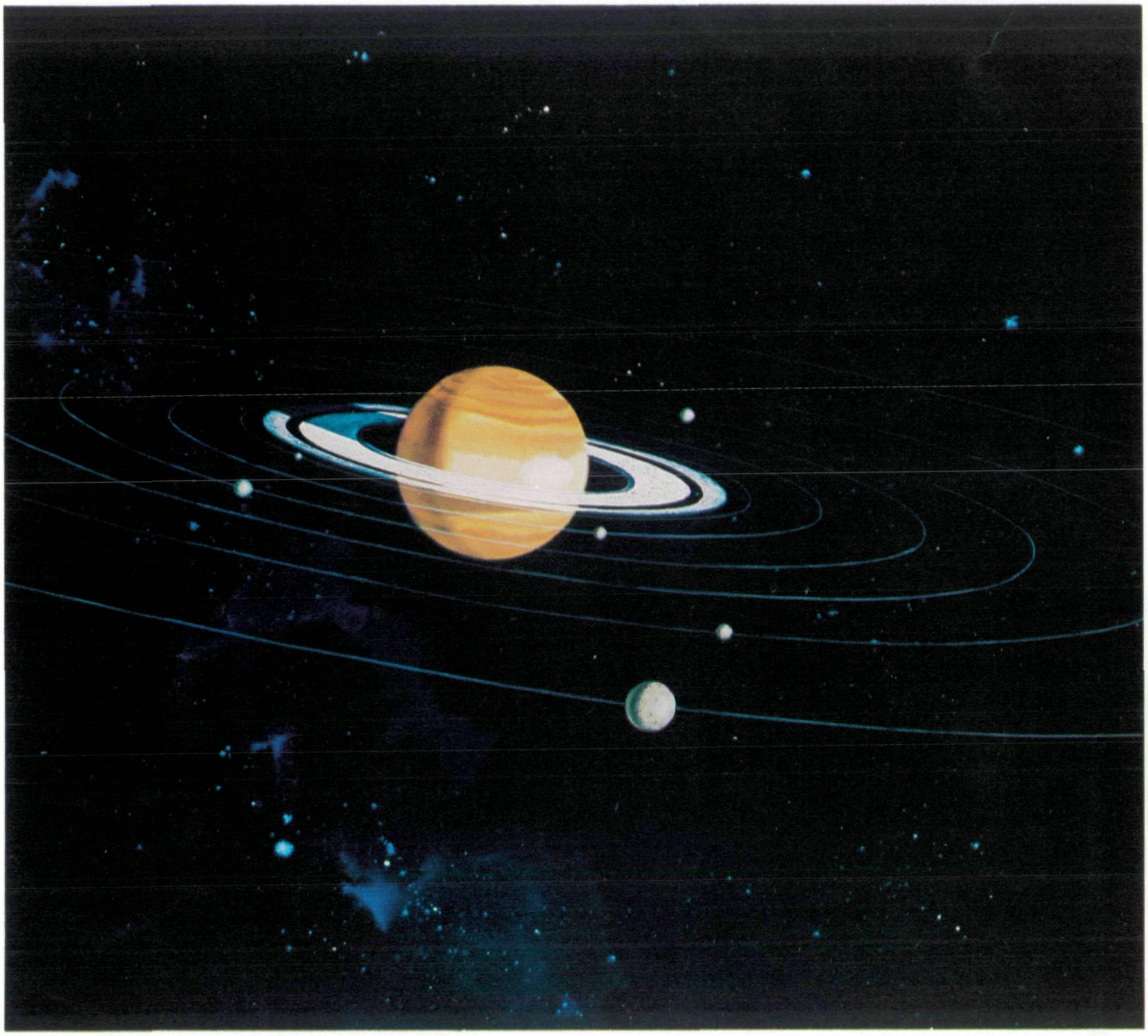
As Voyager 1 draws closer to the ringed planet, the planet's image will grow in the narrow-angle camera's field of view through the fall of 1980. By mid-October, the rings will be too large to be captured in a single frame and scientists back on Earth will combine several frames. Since no one knows how extensive Saturn's magnetosphere is, the fields and particles instruments will begin continuous high-rate data acquisition a month before the closest approach near November 13. Recent radio-astronomy observations from Earth satellites appear to confirm the presence of radio emissions from Saturn, suggesting that a magnetic field and an accompanying trapped radiation belt are present.

On its inbound journey, Voyager 1 will closely examine an object of intense interest to scientists: the big satellite Titan. Titan is 5,800 kilometers in diameter, only slightly smaller than Mars. It is the only satellite known to have a dense atmosphere; the methane that surrounds Titan may be as dense as Earth's atmosphere. Titan's mass is



about twice that of the Moon. Some scientists have speculated that complex organic compounds could have formed in the atmosphere of Titan and now reside on the surface, leading to further speculation that it might even harbor some primitive form of life. Voyager 1 will sail a course only 4,000 kilometers from the surface of Titan, then will fly behind the satellite, cutting off the radio signal to Earth and passing through Titan's solar shadow. Again, the purpose is to analyze the atmosphere, just as Voyager 1 did at Jupiter. Instruments aboard Voyayer 1 will be acquiring unique data: scientists cannot see Titan clearly from Earth.

Saturn has other satellites: ten have been discovered, so Voyager 1 will not be satisfied by its brush with Titan. It will also survey Tethys during the approach to Saturn and its rings, and Mimas, Enceladus, Dione and Rhea afterward.



Beginning in late 1980, Voyager will encounter the ringed planet Saturn and six of its satellites.

Voyager 1 will pass about 140,000 kilometers below Saturn's south pole, snapping hundreds of pictures as it passes. Wide-angle and narrow-angle cameras, polarimetric, ultraviolet and infrared instruments will scan the planet and its rings. The magnetosphere and accompanying regions of charged particles will be charted along the spacecraft's path.

Saturn's rings are not solid – they couldn't be because tidal forces and different rotational speeds at different distances from Saturn would break them up – so Voyager 1's radio signals will be able to trickle through the rings and tell scientists a great deal about those unique objects. And the scientists will learn much more about Saturn's atmosphere and composition as the Sun's rays and the spacecraft radio signals fade and reappear again, as at Jupiter and Titan.

As Voyager 1 flies away from Saturn, its instrument scan platform will look back at the north polar region, the lighted crescent and the tilted rings, collecting long-range information for another month.

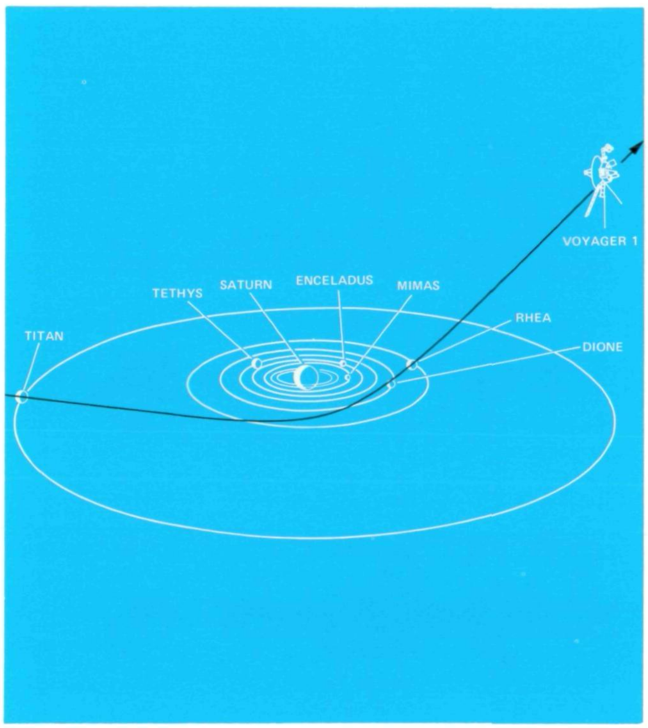
A Second Look at Saturn

Six months after the first encounter ends, the following craft, Voyager 2, will cruise into range in June 1981. While the course of Voyager 1 has been carefully charted, mission planners have left their options open for Voyager 2.

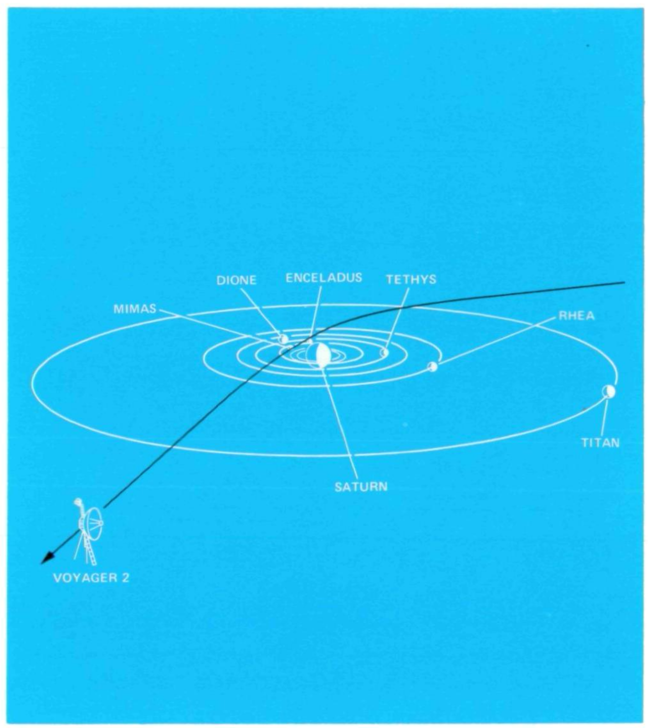
There are two choices. The second spacecraft could repeat the mission of its predecessor, complete with close Titan pass and flight beneath the south pole. But, if all has gone well with the first encounter with Saturn, its rings, and Titan, and if the trailing craft is healthy, controllers and scientists might pick a new path, using Saturn's gravity to boost Voyager 2 toward distant Uranus. This plan calls for another close pass by Saturn, brushing near the outer edge of the rings. Voyager 2 would whip past the ring plane about 38,000 kilometers beyond the outer edge visible from Earth, foregoing a repeat of the close Titan pass. Instead, Voyager 2 would pass about 353,000 kilometers from Titan. Rhea would come within 254,000 kilometers of Voyager; Tethys, 159,000 kilometers; Enceladus, 94,000 kilometers; Mimas, 33,000 kilometers; and finally Dione, 196,000 kilometers distant.

Voyager 2 will flash past Saturn on August 27, 1981, heading ever outward from the Sun, looking back toward Saturn until late September.

By that time, the two Voyagers will have completed close-up examinations of two planets and their satellites. The quantity of planetary data compiled will exceed that amassed by Mariner 9 in its 11-month survey of Mars, to which may be added several years' worth of fields and particles measurements in unexplored regions of the outer solar system. The atmospheres and magnetospheres of the planets will have been analyzed and charted, and five Jovian and six Saturnian satellites will have been surveyed in considerable detail.



As Voyager 1 sails through the Saturnian system, it will pass 140,000 kilometers from the ringed planet's southern polar region, and cruise past six of the ten known Saturnian satellites. This view shows the approximate position of each satellite at closest approach by the spacecraft.



Voyager 2 will gain an even closer look at Saturn. For the Uranus option trajectory, it will pass within 38,000 kilometers of the outer edge of the rings, and again will survey the same six satellites. This simulated view shows the approximate position of each satellite at closest approach by Voyager 2.

Voyager Science Operations

The scientific investigations of the Voyager mission are multipurpose: most are intended to obtain data in a variety of environments. For example, the ultraviolet spectrometer is oriented toward planetary and satellite atmospheres and toward studies of interplanetary and interstellar hydrogen and helium. The magnetic fields experiments will examine the magnetospheres of the planets and the search for the transition between solar and galactic regions.

Thus, it is difficult to separate "planetary" from "interplanetary" instruments and experiments. There is,

VOYAGER SCIENTIFIC INVESTIGATIONS

Experiment	Principal Investigator	Primary Measurements
Cosmic Ray	R. E. Vogt, California Institute of Technology	Energy spectra and isotopic composition of cosmic ray particles and energetic particles in outer planetary magnetospheres.
Imaging Science	Team Leader, Bradford Smith, University of Arizona, Tucson	Imaging of planets and satellites at resolutions and phase angles not possible from Earth. Atmospheric dynamics and surface structures.
Infrared Interferometer Spectrometer	Rudolf Hanel, Goddard Space Flight Center	Energy balance of planets. Atmospheric composition and temperature fields. Composition and physical characteristics of satellite surfaces and Saturn rings.
Low-Energy Charged Particles	S. M. Krimigis, Johns Hopkins University, Applied Physics Lab.	Energy spectra and isotopic composition of low-energy charged particles in planetary magnetospheres and interplanetary space.
Magnetometer	Norman Ness, Goddard Space Flight Center	Planetary and interplanetary magnetic fields.
Photopolarimeter	Charles Lillie, University of Colorado	Methane, ammonia, molecular hydrogen, and aerosols in atmospheres. Composition and physical characteristics of satellite surfaces and Saturn rings.
Planetary Radio Astronomy	James Warwick, University of Colorado	Planetary radio emissions and plasma resonances in planetary magnetospheres.
Plasma	Herbert Bridge, Massachusetts Institute of Technology	Energy spectra of solar-wind electrons and ions, low-energy charged particles in planetary environments, and ionized interstellar hydrogen.
Plasma Wave	Frederick L. Scarf, TRW Systems Group	Dynamics of planetary magnetospheres and satellite perturbation phenomena associated with charged particle-plasma wave interactions. Determination of electron density.
Radio Science	Team Leader, Von R. Eshleman, Stanford University	Physical properties of atmospheres and ionospheres. Planet and satellite masses, densities, and gravity fields. Structure of Saturn rings.
Ultraviolet Spectrometer	A. Lyle Broadfoot, Kitt Peak National Observatory	Atmospheric composition including hydrogen to helium ratio. Thermal structure of upper atmospheres. Hydrogen and helium in interplanetary and interstellar space.

however, another way of grouping: the optical scanners, mounted on the spacecraft's scan platform, have narrow fields of view and must be accurately pointed. They collect radiant energy (light, for example) from their targets and create images or spectral information that permit scientists to understand the physical form or chemical composition of the planets and satellites. Experiments in this group include the imaging-science instruments (the cameras), the infrared interferometer-spectrometer and radiometer, the ultraviolet spectrometer and the photopolarimeter.

A second family of experiments senses magnetic fields and fluxes of charged particles as the spacecraft passes through them. These instruments, fixed to the body of the spacecraft, have various fields of view; their data taken together will provide information on planetary magnetic fields and trapped radiation zones (and indirectly, on interior structures), on Sun-planet and planet-satellite interactions, and on cosmic rays and the outer reaches of the solar plasma. These experiments are the plasma, low-energy charged particles, cosmic ray and magnetic-fields investigations.

A third family of experiments consists of the planetary radio astronomy and the plasma-wave experiments, whose long antennas will listen for radio emissions from Jupiter and will measure waves in the plasma surrounding the planets.

A radio experiment will use S-band and X-band radio links between the spacecraft and Earth to gather information on planetary and satellite ionospheres and atmospheres, and spacecraft tracking data to chart gravitational fields that affect Voyager's course.

The giant antennae of the world-wide Deep Space Network such as the 64-meter dish at Goldstone, California, will receive the spacecraft radio signals and route them on to Mission Operations for analysis.

Mission Operations at the Jet Propulsion Laboratory, Pasadena, California, will be the focal point of Earth activities during the 8-1/2-year mission.

Our solar system may have had its beginnings within an immense, rarified gaseous body such as the Orion Nebula.

What We Hope to Learn

A major objective of the space program is to acquire a basic understanding of the solar system and its origin and evolution. Most theoretical models state simply that the solar system started with a gaseous nebula. Temperature, pressure and density of the gas decrease with distance from the Sun. Formation of the planets is believed to have resulted from accretion of the nebular material. Observed differences in the planets are accounted for by variations in the material and conditions at formation. Knowledge gained at each planet or satellite can be related to others and contributes to overall understanding.

Missions to Mars, Venus, Mercury and the Moon have contributed greatly to this body of knowledge. Each of these planets has its own personality, significantly different from others because of its unique composition and relationship to the Sun. Individual as they are, they are generally related as bodies that originated near the Sun and are composed mainly of heavier elements. They are classified as "terrestrial" planets.

Scientists have known for a long time that Jupiter, Saturn and the other outer planets differ significantly from the terrestrial planets. They have low average densities; only hydrogen and helium among all the elements are light enough to comprise the bulk of these planets. Jupiter and Saturn are sufficiently massive (318 and 95 times Earth's mass, respectively) to indicate that they have retained almost all of their original material. They are, however, only relatively pristine examples of the material from which the solar system formed because, while little or no planetary material has been lost, the planets have evolved during almost 5 billion years. If that evolution can be traced, scientists could obtain an understanding of the early state of that region of the solar system.

Ground-based observations and Pioneers 10 and 11 have determined that Jupiter radiates more energy than it receives from the Sun, and this appears true at Saturn, also. An exact measure of this imbalance is impossible from Earth, since only a portion of the planets' surfaces – the fully lighted dayside – can be seen. It is difficult to study early morning and late afternoon regions, and impossible to see their night sides.

The Interiors: Clues to the Universe

Any discussion of interior temperatures of the outer planets is impossible without knowing how much energy flows from those interiors. Discussion of their evolution requires knowledge of whether the energy is caused by primordial heat, gravitational contraction, or perhaps just energy from a short-period storage mechanism. An understanding of a planet's atmospheric structure and dynamics requires accurate knowledge of the magnitude and location of sources heating that atmosphere.

Jupiter and Saturn, unlike the dense, rocky planets Mercury, Venus, Earth and Mars, are composed mostly of hydrogen and helium – but how much of each? The answer will reveal the general structure of the interior of the planets. If the ratio of hydrogen to helium is the same as for the Sun, differences in observed properties of Jupiter and Saturn can be explained by differences in their mass and in the amount of condensed rock-forming material in the planetary cores – very small for Jupiter and perhaps slightly more for Saturn. If the ratio of hydrogen to helium varies from solar composition, and is lower at Saturn than at Jupiter, then planetary interiors without rocky cores can be inferred.

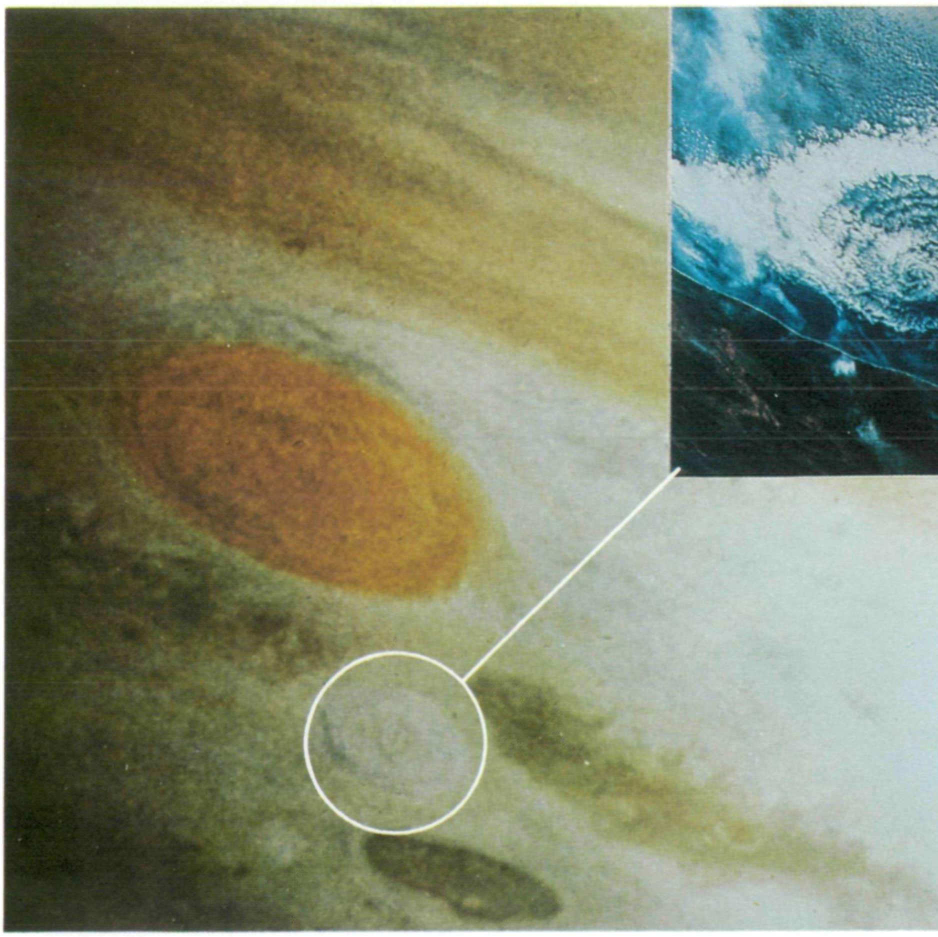
The ratio of hydrogen to helium, therefore, is of fundamental importance. Spectroscopy from Earth offers no answers because cold helium cannot be detected. Attempts to study helium by its effects on other atoms or molecules have been unsuccessful because of the complex atmospheric structure of the outer planets, which have mixed clouds, hazes, and gases that vary over the surfaces.

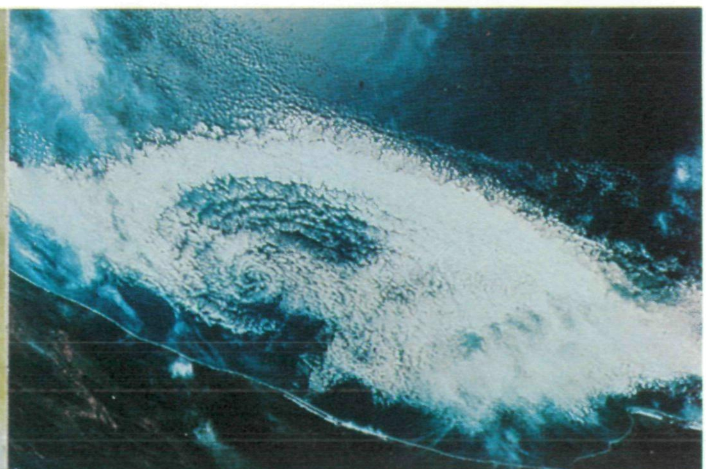
Measurements by the Pioneer spacecraft have determined this hydrogen to helium ratio to be near the solar value, but a more precise determination to be made by the Voyager spacecraft at several depths of the atmospheres of Jupiter and Saturn will provide fundamental bounds on the interior models of both planets.

The magnetic field of a planet is an externally measurable indication of conditions deep in the interior. Jupiter has a magnetic field more than ten times stronger than Earth's. The planet's radio bursts are related to radiation belts that are in turn related to the existence of the strong magnetic field. A variety of related phenomena can be directly measured by instruments near the planet. The detailed study of these phenomena and their interaction with the solar field surrounding the planet will reveal much of what lies at various depths below the clouds.

Direct evidence of a magnetic field and related phenomena is not available for Saturn. Only recently have indirect observations, from Earth-orbiting satellites, indicated the presence of a magnetic field. A close-up comparison of Saturn with Jupiter will be of great interest.

The visible surfaces of Jupiter and Saturn are spectacular. They are not solid surfaces at all, but extremely complex opaque cloud structures with massive turbulence systems – suggesting some of the more severe hurricanes on Earth – that move rapidly across the planet.





Planetary turbulence systems (left) may be similar in nature to this hurricane on Earth (above), photographed by the Apollo astronauts.

Often these storm systems appear, mature and vanish in a few days. One – the famous Great Red Spot – seems to be nearly permanent. It disappears rarely and then for only a short time.

A systematic study of the dynamics and composition of the clouds of Jupiter and Saturn will provide information on the cloud layers and physical mechanisms causing movement. The information, when compared to planets like Earth, Mars and Venus, will permit scientists to test general theories of climatology over widely varying conditions. The studies will be made over several months at each planet.

Evolution of the Satellites

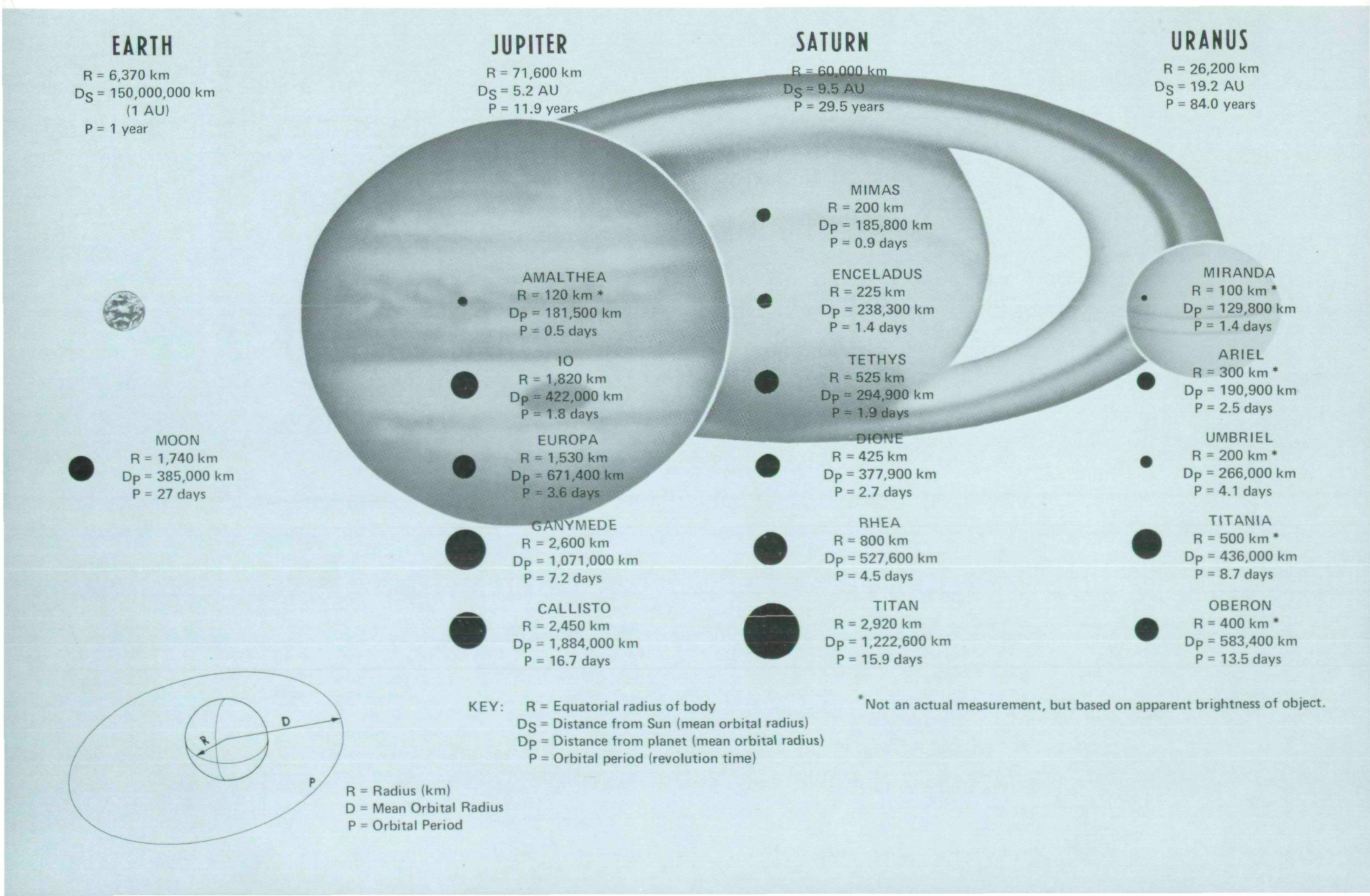
The many satellites of Jupiter and Saturn and Saturn's spectacular rings present opportunities to understand condensed material in the outer solar system. The studies will test theories that predict chemical composition of condensed material according to distance from the Sun, given assumed conditions in the solar nebula. The chemical histories and surface evolution (including records of meteorite impacts) of the satellites will be entirely different from the planets of the inner solar system; they are, therefore, of primary interest for detailed study.

Saturn's satellite Titan, as a specific case, has an atmosphere perhaps as dense as that of Earth. Given the assumed concentrations of methane, and a solid surface on which complex molecules can accumulate, it is a likely site of simple organic compounds and, therefore, an extremely important body for detailed exploration.

The small satellites of Jupiter are similar to asteroids in size. Presumably, they have been pulled from the asteroid belt and captured by the planet. Because they are so small, they rapidly dissipate any heat produced by radioactive decay and should not have changed significantly since formation.

Saturn's rings are often explained as remnants of a gaseous disk that once surrounded Saturn and from which its major satellites formed. Since that description loosely compares with the formation of the planets themselves, detailed study of the rings may provide clues to the behavior of the gaseous disks that might have evolved into the satellites and, indeed, the entire solar system.

Comparison of Earth, Jupiter, Saturn, Uranus and Their Major Satellites



Beyond Saturn

If the option to journey on to Uranus is exercised, Voyager 2 will sail within range of Uranus in January 1986, more than four years after leaving Saturn.

Uranus is markedly different from Jupiter and Saturn. It is tilted so far on its axis that the poles lie almost in the plane of the ecliptic. Thus, in contrast to the other planets, Uranus lies on its side. It circles the Sun once in 84 years. Once in each orbit the Sun shines directly down on the north pole; 42 years later the south pole is lighted. In 1986, the orientation of Uranus will allow Voyager 2 to fly almost perpendicular to the equatorial and satellite plane. Voyager 2 will get a good look at any magnetosphere and plasma cloud that may be present, and could photograph the sunlit hemisphere of Uranus and all of its satellites. The spacecraft will also provide a first close observation of the newly discovered rings of Uranus. Voyager 2 would then sail out through the planet's wake, looking back at the dark southern hemisphere.

Years after launch, perhaps 30 times farther from the Sun than Earth is, their attitude control gas spent, the two Voyagers will be unable to respond to attitude correction commands from their Earth masters, and communications will fade and disappear as they drift out of range.

Their mission of discovery and exploration complete, the two craft will sail on forever.

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