JUPITER

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Introduction

Beyond Mars and the asteroid belt, in the outer regions of our solar system, lie the giant planets of Jupiter, Saturn, Uranus and Neptune. In 1972, NASA dispatched the first of four spacecraft slated to conduct the initial surveys of these colossal worlds of gas and their moons of ice and rock. Jupiter was the first port of call.

Pioneer 10, which lifted off from Kennedy Space Center in March 1972, was the first spacecraft to penetrate the asteroid belt and travel to the outer regions of the solar system. In December 1973, it returned the first close-up images of Jupiter, flying within 132,252 kilometers (82,178 miles) of the planet's banded cloud tops. Pioneer 11 followed a year later. Voyagers 1 and 2 were launched in the summer of 1977 and returned spectacular photographs of Jupiter and its family of satellites during flybys in 1979.

These travelers found Jupiter to be a whirling ball of liquid hydrogen and helium, topped with a colorful atmosphere composed mostly of gaseous hydrogen and helium. Ammonia ice crystals form white jovian clouds. Sulfur compounds (and perhaps phosphorus) may produce the brown and orange hues that characterize Jupiter's atmosphere.

It is likely that methane, ammonia, water and other gases react to form organic molecules in the regions between the planet's frigid cloud tops and the warmer hydrogen ocean lying below. Because of Jupiter's atmospheric dynamics, however, these organic compounds, if they exist, are probably short-lived.

The Great Red Spot has been observed for centuries through telescopes on Earth. This hurricane-like storm in Jupiter's atmosphere is more than twice the size of our planet. As a high-pressure region, the Great Red Spot spins in a direction opposite to that of low-pressure storms on Jupiter; it is surrounded by swirling currents that rotate around the spot and are sometimes consumed by it. The Great Red Spot might be a million years old.

Our spacecraft detected lightning in Jupiter's upper atmosphere and observed auroral emissions similar to Earth's northern lights at the jovian polar regions. Voyager 1 returned the first images of a faint, narrow ring encircling Jupiter.

Largest of the solar system's planets, Jupiter rotates at a dizzying pace, once every 9 hours 55 minutes 30 seconds. The massive planet takes almost 12 Earth years to complete a journey around the Sun. With 16 known moons, Jupiter is something of a miniature solar system.

A new mission to Jupiter, the Galileo Project, is under way. After a six-year cruise that takes the Galileo Orbiter once past Venus, twice past Earth and the Moon and once past two asteroids, the spacecraft will drop an atmospheric probe into Jupiter's cloud layers and relay data back to Earth. The Galileo Orbiter will spend two years circling the planet and flying close to Jupiter's large moons, exploring in detail what the two Pioneers and two Voyagers revealed.

Jupiter Through the Telescope

* Jupiter is a beautiful sight seen with the naked eye on a clear night, but only through a telescope does it begin to reveal its magnificence. The most promi-

nent features are alternating light and dark bands, running parallel to the equator and subtly shaded in tones of blue, yellow, brown, and orange. However, these bands are not the planet's only conspicuous markings. In 1664 the English astronomer Robert Hooke first reported seeing a large oval spot on Jupiter, and additional spots were noted as telescopes improved. As the planet rotates on its axis, such spots are carried across the disk and can be used to measure Jupiter's speed of rotation. The giant planet spins so fast that a jovian day is less than half as long as a day on Earth, averaging just under ten hours.

* During the nineteenth century, observers using increasingly sophisticated telescopes were able to see more complex detail in the band structure, with wisps, streaks, and festoons that varied in intensity and color from year to year. Furthermore, observations revealed the remarkable fact that not all parts of the planet rotate with the same period; near the equator the apparent length of a jovian day is several minutes shorter than the average day at higher latitudes. It is thus apparent that Jupiter's surface is not solid, and astronomers came to realize that they were looking at a turbulent kaleidoscope of shifting clouds.

* Although the face of Jupiter is always changing, some spots and other cloud features survive for years at a time, much longer than do the largest storms on Earth. The record for longevity goes to the Great Red Spot. This gigantic red oval, larger than the planet Earth, was first seen more than three centuries ago. From decade to decade it has changed in size and color, and for nearly fifty years in the late eighteenth century no sightings were reported, but since about 1840 the Great Red Spot has been the most prominent feature on the disk of Jupiter.

* It was not until the twentieth century that the composition of the atmosphere of Jupiter could be measured. In 1905 spectra of the planet revealed the presence of gases that absorb strongly at red and infrared wavelengths; thirty years later these were identified as ammonia and methane. These two poisonous gases are the simplest chemical compounds of hydrogen combined with nitrogen and carbon, respectively. In the atmosphere of Earth they are not stable, because oxygen, which is highly active chemically, destroys them. The existence of methane and ammonia on Jupiter demonstrated that free oxygen could not be present and that the atmosphere was dominated by hydrogen‹a reducing, rather than oxidizing, condition. Subsequently, hydrogen was identified spectroscopically. Although much more abundant than methane or ammonia, hydrogen is harder to detect.

* In the 1940s and 1950s the German American astronomer Rupert Wildt used all the available data to derive a picture of Jupiter that is still generally accepted. He noted that both the low total density and the observed presence of hydrogen-rich compounds in the atmosphere were consistent with a bulk composition similar to that of the Sun and stars. This “cosmic composition” is dominated by the two simplest elements, hydrogen and helium, which together make up nearly 99 percent of all the material in the universe. Wildt hypothesized that the giant planets, because of their large size, had succeeded in retaining this primordial composition, whereas the hydrogen and helium had escaped from the smaller inner planets. He also used his knowledge of the properties of hydrogen and helium to calculate what the interior structure of Jupiter might be like, concluding that the planet is mostly liquid or gas. Wildt suggested that there probably was a core of solid material deep in the interior, but that much of Jupiter is fluid‹extremely viscous and compressed deep be-

low the visible atmosphere, but still not solid. The atmosphere seen from above is just the thin, topmost layer of an ocean of gases thousands of kilometers thick.

* According to a theory formulated in 1958, the interior of Jupiter includes a large core of metallic hydrogen.

* Pioneer 10, in 1973, and Pioneer 11, in 1974, made the first flybys of Jupiter; both spacecraft survived passage through the asteroid belt and through the Jovian trapped radiation. Among the findings from these spacecraft were the following: * Aside from its polar flattening, Jupiter is very symmetrical and has no gravitational anomalies; it behaves like a liquid planet.

* Jupiter is slightly more massive than had been indicated from ground-based observations.

* As suggested from ground-based measurements, Jupiter emits twice as much energy as it receives from the Sun.

* The temperature at the center of the planet may be 30,000° C.

The Atmosphere

* From ground-based studies, it was deduced that the atmosphere of Jupiter must consist mostly of hydrogen and helium, in an approximately 2 to 1 ratio. The bright bands in the atmosphere (“zones”) are cooler than the dark ones (“belts”).

* A theory proposed in 1986 interprets the Great Red Spot as the top of a

rotating column in the atmosphere.

* Among the results of the Pioneer 10 and 11 missions were

* The general banded structure of the Jovian atmosphere is not present near the poles; there, oval circulation patterns develop.

* At the poles, a thick, aerosol-free, or “blue sky,” atmosphere was found.

* The bright zones consist of rising cloud masses at higher altitudes, while the belts are descending masses that allow a deeper view into the atmosphere.

* Two cloud layers are present; the thick, low cloud deck is topped by a thinner, clearer region.

* Detailed study showed rapid motions among the clouds and changes in the wind speeds.

* Bright plumes of warm material were observed rising from deep in the atmosphere.

* Changes in the flow patterns of the Great Red Spot were observed between 1973 and 1974; the Great Red Spot and other features were interpreted as hurricane-like storms.

* Helium was detected, confirming the earlier deduction of the Jovian atmospheric composition.

* Voyager 1 and Voyager 2 flew past Jupiter and its moons in 1979; among the findings from this pair of spacecraft were

* Eruptions of warmer material from below are signalled by brightenings followed by cloud spreading.

* Along the boundaries of the belts and zones, there occur atmospheric jet streams, plumes, and extensive turbulence.

* There is actual mass movement, rather than simply wave motions, in the Jovian atmosphere. * An east-west wind structure is present in the polar regions. * The Great Red Spot rotates counterclockwise in about 6 days, as estimated from ground-based observations.

* The fraction of helium by volume in the Jovian atmosphere is 0.11.

* Aurorae were discovered in the polar regions and are related to the magnetic field lines and currents between Jupiter and its moons.

* Lightning “superbolts” were detected in the cloud tops.

* There is intense ultraviolet emission from the atmosphere.

* Minor components of the Jovian atmosphere that have been detected at various times include deuterium (heavy hydrogen) compounds; organic molecules such as ethane and acetylene; water vapor (found using the Kuiper Airborne Observatory in 1975); carbon monoxide; phosphine (PH3); and germane (GeH4).

The Magnetic Field and Trapped Radiation of Jupiter

*The discovery of naturally generated radio bursts from Jupiter was accomplished with a ground-based radio telescope in 1955. Theory indicated that a

strong magnetic field must be present in order to account for the bursts, and additional radio observations showed that the occurrence of many bursts is related to the position of the Jovian moon Io.

*Among the findings of Pioneer 10 and 11 were

* The magnetic field was detected and found to be huge. The bow shock of the Jovian magnetosphere had a measured width of 26 million kilometers (16 million miles). The Jovian magnetic tail extends to beyond the orbit of Saturn. If the magnetosphere were visible in the sky from Earth, it would appear larger than the Sun or Moon.

* The Jovian magnetic field is l0 times stronger than Earth's and contains 20,000 times as much energy.

* The axis of the magnetic field is tilted 11 degrees from the Jovian rotation axis and is offset from the center of Jupiter in a manner similar to the axis of the Earth's field.

* The Jovian magnetic field has the"north" magnetic pole is at the south pole of Jupiter.

* The magnetic field fluctuates rapidly in size on the sunward side of Jupiter because of pressure variations in the solar wind, an effect studied in further detail by the two Voyager spacecraft.

* Energetic protons were found and measured in the Jovian radiation belt.

* It was discovered that streams of high-energy atomic particles are ejected from the Jovian magnetosphere and travel as far as the orbit of the Earth.

* Electric currents were detected flowing between Jupiter and some of its moons, particularly Io.

* Among the findings of Voyager 1 and 2 were

* Within the Jovian magnetosphere is a huge sheet of plasma (a gas of electrically charged atomic particles), 4.8 million kilometers (3 million miles) in diameter. The plasma sheet rotates along with Jupiter and its magnetic field.

* Some of the magnetospheric plasma has a remarkably high temperature, in the millions of degrees. Among the high energy particles in the plasma are ions of hydrogen, sulfur, and oxygen.

* A sulfur-rich plasma, which was not present in 1973, was detected near Io, with a temperature of about 100,000° C.

* The electrical current between Jupiter and Io was measured at about 5 million amperes.

* It was found that radio emissions may be generated in the plasma near

The Moons and Ring of Jupiter

* Ground-based studies of the jovian moons in the 1970's revealed the presence of two additional small moons and the existence of water ice on the surfaces of the three outermost Galilean satellites, Europa, Ganymede, and Callisto.

* Findings about the jovian satellites from Pioneer 10 and 11 included:

* The two outermost Galilean moons, Ganymede and Callisto, are less dense

than the Earth's Moon.

* Io was found to be 28 percent more massive than had been calculated from groundbased observations and to be 1.22 times more massive than our Moon.

* A thin atmosphere, about 1/20,000 of the density of Earth's atmosphere and extending to about 115 kilometers (70 miles) above the surface was discovered on Io.

* A cloud of sodium vapor around Io and its orbit, detected from the ground, was detected and found to be immersed in a cloud of hydrogen as well.

Results of the Voyager 1 and 2 missions included:

* Three additional moons were discovered.

* Amalthea, the small inner moon of Jupiter, was found to have an elliptical shape. In effect it is a big rock, about 265 x 140 kilometers (165 x 87 miles) in size.

* Volcanic eruptions were discovered on Io, the first evidence of active volcanism found outside the Earth. The volcanism is probably induced by tidal heating. The erupted plumes extend up to 320 kilometers (200 miles) above the surface, and the volcanic activity varies over times of a few months.

* A hot spot on Io, 150° C warmer than the rest of the surface, and associated with volcanic features, was discovered.

* Europa was found to be a world of essentially flat terrain, with virtually no topographic relief. It is marked by intersecting linear features, not cracks, and the surface is very young, as indicated by the lack of impact craters.

* Both cratered and grooved terrains are present on Ganymede; the icy crust of this moon appears to have been globally deformed.

* Ganymede was found to produce distinct disturbances in the jovian magnetic field and trapped radiation belts as far as 200,000 kilometers (124,000 miles) away.

* Callisto's crust is ancient and heavily cratered, with large impact basins.

* A ring around Jupiter was discovered inside the orbit of the innermost moon. It apparently extends down to the top of the jovian atmosphere.

Source: NASA