THE JET PROPULSION LABORATORY SPACE EXPLORATION: PAST, PRESENT AND FUTURE

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Abstract

The most recent scientific results from space exploration carried out by the Jet Propulsion Laboratory (JPL) are discussed.

To understand these results, a brief background of JPL's history is presented, followed by a description of the Deep Space Network, JPL's system of antennas which communicates with spacecraft.

The results from the missions of Voyager 1 and Voyager 2 are described. The atmosphere, rings, satellites and magnetospheres of Jupiter, Saturn, Uranus and Neptune are discussed with particular emphasis on novelty of the discoveries and the challenges encountered in explaining them.

A brief discussion of the impact of spray research upon space exploration follows. This is because most recently launched missions used liquid fueled rockets to escape Earth's gravity.

A summary of future missions and the National Aeronautics and Space Administration's new policies is presented in the conclusion.

Introduction

The human race has always had a fascination with outer space. Our ancestors looked at the night sky as a curtain revolving in front of their eyes and tried to make some sense of what they were seeing by organizing the tiny dots of lights (which they were calling indiscriminately "stars"), into constellations; thus the tales of astrology were born. Later, the same curiosity replaced the tales of astrology by the science of astronomy; the invention of the telescope was instrumental in bringing about this change. People had been observing the Universe for centuries using increasingly more powerful telescopes, when space exploration came about revolutionizing our concept of the Universe, the solar system and the understanding of our own place in the Universe.

The Jet Propulsion Laboratory (JPL) has been instrumental in space exploration ever since its inception, and remains at the forefront of the quest for understanding the Universe's past, its future, and how this tiny speck in the Universe, which we call Earth, and which is so important to us, could be affected by changes which happen in other parts of the solar system or even further from us.

This paper is devoted to discussing the JPL role in space exploration. A brief JPL history is followed by a description of the Deep Space Network which is JPL's communication center with space. Further, some JPL missions will be discussed and the scientific accomplishments of the missions will be pointed out. I will also briefly discuss the relationship between spray research, which is my own specialty, and space exploration. Finally, I will summarize where we stand after so many years of space exploration and I will mention the challenges of the future missions.

Space exploration is the result of the effort of many more people than those whose names appear on scientific publications. Sometimes discoveries are made by people who are only analyzing data. These discoveries are not necessarily published by the very same people in technical journals. Thus, it is very difficult to give proper credit for discoveries and the understanding obtained from the discoveries. For this reason this paper contains no references, as it obviously impossible to acknowledge appropriately in a field as wide as space exploration.

Brief History of JPL

JPL owes its existence to Theodore von Karman, a Caltech professor who conducted pioneering work in solid-fueled and liquid-fueled propulsion. In the 1930's von Karman and his students performed what was considered at that time some "odd experiments in a desolate spot in the Arroyo Seco north of Pasadena", as recounts one of the students who participated in those experiments. The first successful rocket firing took place in 1936 and by the 1940's came the first application of this basic research -- the jet-assisted takeoff (JATO) for aircraft. At that time the Laboratory was part of the U.S. Army, but two months after the National Aeronautics and Space Administration (NASA) was created in 1958, JPL was transferred to NASA's jurisdiction. Since then JPL has specialized in unmanned space exploration. In the 1960's, JPL conceived and successfully executed the Ranger and Surveyor missions to the moon. At the same time JPL initiated the Mariner missions to Mercury, Venus and Mars which continued during the 1970's.

The Viking mission to Mars was launched in 1975 and was by far the most complex mission undertaken by JPL. JPL not only constructed the two orbiter spacecraft, but it also was responsible for the management of the mission including the building of two Mars landers as well as coordination between several NASA centers and private U.S. aerospace firms.

The JPL Voyager Project stands out as having given the most profitable of all unmanned explorations to date, besides being the most long-lived planetary mission. The twin spacecraft Voyager 1 and Voyager 2 were launched in 1977. They explored Jupiter in 1979 and Saturn in 1980 -1981. Then Voyager 2 went on to an encounter with the planet Uranus in 1986 and a flyby of Neptune in 1989. Voyager 1 followed a different course by taking in the early 1990's pictures of many objects of the solar system. Neither Voyager has finished yet its mission; both are continuing to travel into outer space and are expected to provide confirmation about the Sun's energy environment. Both spacecraft are expected to be operational until perhaps the second decade of the 21st century.

More recently, JPL missions (1989-1990) have been launched using NASA's Space Shuttle. Magellan has been and is still studying planet Venus using a sophisticated radar imager which penetrates through the clouds and enables the mapping of the surface. Magellan arrived at Venus in August 1990 and is expected to finish its present mission by May 1991, although an extension of that mission is investigated.

Galileo started its mission to Jupiter in October 1990 and uses a sophisticated concept called "gravity assist" boosts to save on the fuel needed for such a long mission. Galileo's six-year flight trajectory involves first going to Venus once and then to Earth twice to obtain the boosts for its long flypath. When Galileo arrives at Jupiter in 1995, a probe will descend into its atmosphere to obtain data on the chemical nature and the physical conditions there Galileo will remain in orbit around Jupiter for about two years, investigating not only the planet, but also its major satellites.

In October 1990, a probe bound to other parts of the solar system, Ulysses, was launched as a joint project with the European Space

Agency. Ulysses will travel out of the ecliptic (the plane in which all planets orbit the Sun) and travel towards the Sun's north and south poles. Again, the gravity assist concept is been used, with Ulysses having flown first by Jupiter in February 1992 to obtain a boost which sends it in an orbit almost perpendicular to the ecliptic plane. Ulysses will accomplish its mission by September 1995.

Other important missions that JPL carried out are the Infrared Astronomical Satellite (IRAS) and the Shuttle Imaging Radar (SIR-A and SIR-B). IRAS was launched as a joint project with' the Netherlands and the United Kingdom in 1983, and is a telescope placed in the Earth's orbit which can map the sky in the infrared wavelengths invisible to the eye. Not only has IRAS discovered new comets, but most important it found evidence of an originating planetary system around the star Vega located 26 light-years from Earth. The SIR experiments were conducted in the cargo bay of the Space Shuttle and involved sophisticated radar techniques to obtain pictures of the Earth's surface showing features which cannot be detected using normal photography. (For example, the lost city of Ubar has been detected by the SIR experiments.) Most recently, in September 1992, the Mars Observer was launched. Its mission is both to make highly detailed maps of Mars and also to relay data from a Russian Mars mission to be launched in 1994.

The success of JPL's space program is not only due to the design and construction of the spacecraft, but also to the communication system for directing missions, and receiving and interpreting data -- the Deep Space Network (DSN).

The Deep Space Network

The Deep Space Network is a unique worldwide system which enabfes navigation, tracking and communication with spacecraft during missions. The DSN is the communication link between the instruments on board of the spacecraft and the laboratories on Earth which allows the transmitting of instructions to the spacecraft and the reception of data from the spacecraft. It is through this system that one knows the direction of the flight, velocity and range from Earth, and it is also through this system that one receives the scientific data from the missions. It is also through this system that one sends commands to the spacecraft to direct navigation.

The network was initiated in 1958 and consisted at that time of three stations that received data from the first U.S. satellite, Explorer 1. Over the years, the DSN has evolved to include 12 deep-space antenna stations located strategically so as to cover at all times the trajectory of any spacecraft launched into space. The DSN antennas consist of low-noise receivers and high power transmitters.

The main centers of DSN are three Deep Space Communications Complexes (DSCC's) which are located at Goldstone (Southern California's Mojave Desert), near Madrid (Spain) and near Canberra (Australia). These three locations are about 120 degrees apart in longitude so that as the Earth turns on its axis, a distant spacecraft will almost always be within view of one of those stations.

The DSCC is monitored by the Network Operations Control Center (NOCC) at JPL, and the DSN Ground Communications Facility (GCF) provides the communication link between the DSCC and the NOCC.

Each of the DSCC's stations has four antennas: a 64 m diameter antenna soon to be upgraded to a 70 m antenna, a 26 m antenna and two 34 m antennas. One of the 34 m antennas is a high-efficiency antenna providing the capability needed for outer planet missions.

The different size antennas provide the system with different capabilities. For example, the 64 m antennas are the most sensitive and are used in the deep space missions; the '26 m antennas are used to communicate with some spacecraft in Earth orbit; and the 34 m antennas are used for both types of mission. The 64 m and 34 m antennas are operated by a remote control system.

The DSCC's are endowed additionally with transmitting, receiving, data handling and inter-station communication equipment. One interesting technique which is used to combine the information from several DSCC's is that of

Very Long Baseline Interferometry (VLBI) whereby measurements made by two or more widely spaced antennas can be combined to yield the resolving power of one giant antenna which spans theoretically the distance between the antennas.

Creative techniques are always needed when spacecraft are very far from Earth, such as during the exploration of Uranus or Neptune. The x-band radio signals received from Voyager 2 at Neptune were less than one tenth as strong as those received from Jupiter and less than one half as strong as those received from Uranus. Thus, because of the weaker signals, data had to be sent at a lower rate in order to be clearly received by the ground stations. When spacecraft are very far from Earth, not only are signals weak, but they are also very noisy. Because of the reduction in the signal-to-noise ratio when data was transmitted from Uranus, several DSN antennas were arrayed and combined with the Parkes radio astronomy 64 m antenna and this maintained the signal to be only one half of what it was at Saturn. Saturn is at 10 AU (Astronomical Unit -- the average distance between Earth and Sun) from the Sun, whereas Uranus is 19 AU from the Sun and thus without this creative technique the strength of the signal would have fallen off by one quarter at Uranus when compared to Saturn. The same technique was used during the Neptune encounter when the DSN was coupled to the Parkes Radio Telescope and to the National Radio Astronomy Observatory's Very Large Array (VLA) near Socorro in New Mexico.

Although in principle the DSN is only a communication system, in fact it has also been used as a scientific instrument to investigate natural radio sources such as pulsars and quasars, to study the surface of planets and Saturn's rings using radar techniques, to test theories of relativity using celestial mechanism experiments, and to pursue lunar gravity and Earth physics experiments. The most speculative of the investigations carried with the DSN is the Search for Extraterrestrial Intelligence (SETI).

Although the capabilities of the DSN seem very impressive, even more impressive are the scientific findings from some of the JPL space missions. In the following, some of these findings associated with the four gas giant planets of the solar system will be discussed,

The Jupiter Voyager 1 and 2 Missions

During the encounter of the two Voyager spacecraft with Jupiter, more than 33,000 pictures of Jupiter and its five major satellites were taken.

One of the greatest surprises of these missions was the finding of the first active volcano on another body in the solar system, namely on 10. It appears that volcanic activity on 10 affects the entire Jovian system because matter ejected from the volcanoes (mainly sulfur, oxygen and sodium) can be detected as far as the outer edge of Jupiter's magnetophase (the region of space surrounding the planet that is primarily influenced by the planet's magnetic field). Interestingly enough, no sulfur was detected by the earlier Pioneers 10 and 11 that flew by Jupiter in late 1973 and 1974, so it is now believed that some changes occurred in the 4 1/2 years between the Pioneer and Voyager missions.

The scientific understanding of the Jovian system can be summarized as followed:

Jupiter's Atmosphere

Atmospheric structures on Jupiter are of a variety of sizes, but one common aspect to all of them is that they were seen to move with uniform velocities. This suggests that it is mass motion (movement of material) rather than wave motion (movement of energy through a relatively stationary mass) that induces these structures. These structures changed in brightness rapidly with a resulting spreading of cloud material suggesting upward and downward convective activity.

A pattern of east-to-west winds was detected up to 60° north and south latitudes, but the largest organized atmospheric feature identified was the Great Red Spot which had first been seen by Galileo more than three hundred years ago. This is a cloud mass moving in a counterclockwise (anticyclonic) direction with a period of 4-6 (Jovian) days at the outer edge; near the center, the motions are small and almost random. The Great Red Spot interacts with other smaller, but similar atmospheric features and those features also interact with each other.

Similar to our own northern lights on Earth, there are auroral Jovian emissions which were observed both in ultraviolet and visible light. These seem to be associated with material ejected from 10 that spirals along magnetic field lines and falls into the Jovian atmosphere. Consistent with the fact that the earlier Pioneer missions did not detect the volcanic activity, they did not detect these auroral emissions either.

Also similar to the electrical activity in Earth's high atmosphere, cloud-top lightning bolts were detected on Jupiter as well.

Both the atmospheric and the ionospheric characteristics were measured by the Voyagers. The atmospheric temperature at a pressure of 5-10 millibars (compared to about 1000 millibars near the Earth surface) is about 160 K (compared to 293 K considered "room" temperature on Earth). Jupiter, like Saturn, Uranus and Neptune does not have a solid surface as it consists only of gas. An interesting feature is an inversion layer (warm layer above a cold layer) near the 150- millibar level. In the ionosphere the temperature reaches 1,100 K, and this change of temperature with altitude had not been observed previously by the Pioneer missions, thus leading to the belief that there have been indeed large temporal or spatial changes in the Jovian ionosphere. Finally , the composition of Jupiter's upper atmosphere is such that volumetric ratio of helium to hydrogen is about 12%.

Satellites and Ring

Among all Jovian satellites, 10 was the one reserving most surprises with its nine currently erupting volcanos. These nine volcanoes were observed by Voyager 1, but by the Time Voyager 2 arrived at Jupiter only eight were active. Plumes from the volcanoes were more than 300 km high with material being ejected to 1000 m/see. This is to be compared for example with data from Mt. Etna on Earth -- one of the most explosive volcanoes -- showing ejection velocities of 50 m/see.

The volcanic activity on 10 is thought to be controlled by heating associated with perturbations in lo's orbit around Jupiter (tidal pumping). Since lo's orbit is influenced by two other Jovian satellites -- Europa and Ganymede -- this pumping action causes tidal bulging as high as 100 m on lo's surface (compared with typical tidal bulges of 1 m on Earth).

A large hot spot (290 K compared to the surrounding 130 K) was identified in 10. Although scientists believe it might be a lava lake, its surface is not composed of molten material (according to its temperature).

Europa, the smallest of Jupiter's satellites, surprised investigators by its large number of interesting linear features lacking topographic relief. These features are not yet totally explained, although models of Europa's interior showing the possibility of internal oceans about 50 km deep below a thin (5 km) water ice crust, suggest that there might be small internal activity (one tenth or less than on lo) due to tidal heating.

Before the Voyager encounters it was thought that Titan (orbiting around Saturn), was the largest Satellite in the solar system. As it turns out, Ganymede, another Jovian satellite, is larger than Titan. Ganymede displays two kinds of terrain -- cratered and grooved -- suggesting that its ice-rich crust suffered from tension reduced by global tectonics.

The most prominent characteristic of Callisto is its ancient, heavily cratered crust showing rings (but no topographic relief) of enormous impact basins which apparently were erased by ice-containing flows over geologic times,

Amalthea, another satellite, was shown to be elliptical, and between its orbit and lo's, a new satellite, Thebe was discovered.

Investigators were surprised to find out that Jupiter, just like Saturn and Uranus, has a ring around it with an outer edge orbiting at about 129,000 km from the center of the planet This ring is only 30 km thick, but it is 6,000 km wide at its brightest portion with ring material extending 50,000 km downward up to the top of the Jovian atmosphere and outward as far as the orbit of Amalthea. Just outside the ring, two new satellites, named Adrastea and Metris, were discovered.

Magnetosphere

In the flux tube flowing between Jupiter and 10, an electric current of about 5 x 10^6 A was detected, which is five times more than it had been predicted before the Voyager 1 mission. The stronger current had twisted the flux tube 7,000 km from the predicted location, and thus Voyager 1 did not fly through if as had been planned.

A cold plasma rotating with Jupiter and containing sulfur and oxygen ions was detected. A hot plasma having similar composition was discovered near the Jovian magnetopause. The sulfur is thought to originate from lo's volcanoes.

10 has itself a plasma torus with electron densities in excess of 4,500 electrons/cm^3. Plasma oscillations in the torus are thought to induce kilometric radio emissions (1 O KHz - 1 MHz) coming from Jupiter.

Voyager 1 also discovered the existence of a plasma flow, rotating with the planet at a 10-hour period, on the solar side of the magnetosphere. On the antisolar side of the magnetosphere, Voyager 1 confirmed the transition from the magnetosphere (enclosed magnetic field lines) to a magnetotail. Voyager 2 observed this magnetotail extending at least to the orbit of Saturn.

Whistler wave emissions confirmed the existence of lightning bolts in the Jovian atmosphere, as it had been suspected from Voyager photographs. It is thought that lightning provides energy for a wide range of Jovian phenomena.

The Saturn Voyager 1 and 2 Missions

Voyager 1 encountered Saturn in November 1980 and Voyager 2 arrived at Saturn in August 1981. Their findings changed our understanding of Saturn and some of the facts collected from those missions are still puzzling us.

Saturn's atmosphere

Data from Voyager 1 show that the volumetric ratio of helium to hydrogen is 7°/0 in Saturn's upper atmosphere. Since it is expected that Saturn's internal helium volumetric proportion is the same as Jupiter's and the Sun's, this suggests that the heavier helium is slowly sinking through the hydrogen. This could also explain why Saturn radiates an excess heat over the energy it receives from the Sun.

Voyager 2 identified long-lived oval atmospheric features which were tilted in the east-west shear zones. These features were generally smaller than on Jupiter.

Winds tend to blow at ferocious speeds on Saturn, with maximum speeds of 500m/sec near the equator. The winds blow mainly in the easterty direction at latitudes lower than 35° and this suggests that these winds are not only a feature of the cloud layer, but that they extend inward to at least 2,000 km, At greater latitudes the wind velocity falls, and the direction of the winds alternates eastward and westward.

Upper-atmospheric temperatures were measured at different pressures. Minimum temperatures of 82K were encountered at the 70-millibar level, with a maximum of 143 K at the 1,200 millibar level (the deepest level probed). Colder temperatures were found near the north pole than at mid-latitudes, suggesting that this may be a seasonal effect.

A great puzzle remains the finding of aurora-like emissions of hydrogen at mid-latitudes. Auroras were also observed at higher latitudes, just like on Earth and Jupiter, and those are thought to lead to the formation of complex hydrocarbon molecules that are carried towards the equator. The mechanism for those high latitude auroras is known to be the bombardment by electrons and ions which could not exist in abundance at lower latitudes.

Both Voyagers measured the rotation rate of Saturn to be 10 hours, 39 minutes and 24 seconds.

The Rings

The ring structure offered the most

surprises to investigators and many of the details of the structure remain unexplained.

A successful explanation was found for the structure of the B-ring which has variations in density of the ring material. It turns out that these density waves are caused by the gravitational effect of Saturn's satellites.

Most of the structure in the ring material is thought to be transitory, except for large-scale gaps such as the Cassini and Encke Divisions. The extraordinary resolution of the photographs showed that the edges of the rings exhibiting gaps are so sharp that the ring must be less than 200 m thick, Whenever a gap exists, there seems to be eccentric ringlets. Crumping and kinking of material was also found and investigators hypothesize that it may be due to the presence of undetected satellites. Examples of discontinuous ringlets were found in Encke's Gap (in the A-ring gap) and at least one of the ringlets has multiple strands.

Another example of braided or twisted strands was observed by Voyager 1 in the F-ring. The higher resolution of Voyager 2 showed five separate strands in a region that had no braiding and oniy a small region where the ring appeared twisted. These twists are thought to be due to the gravitational perturbations of two shepherding satellites.

Spokes found in the B-ring were aiso a surprise. These spokes had scattering characteristics of dust-sized particles. Narrower spokes having a radial alignment are believed to be more recently formed, whereas wider and iess radial spokes seem to have formed earlier, and follow Keplerian orbits.

The variation in the general dimensions of the rings around Saturn is still unexplained. The rings' outer edges are elliptical and do not follow Kepierian orbits since Saturn is at the center of the ellipse rather than at one focus. Satellites, such as Minas may be responsible for these effects.

Satellites

Titan is Saturn's largest satellite, and the oniy one known to have a dense atmosphere. Investigators believe that they see in this dense atmosphere a chemistry similar to that which existed on primeval Earth. Titan's surface could not be seen through the photochemical haze layer which lingers about 300 km above Titan's surface. Titan's atmosphere is composed of mostly nitrogen (just iike Earth) and near the surface the pressure is 1.6 bars, and the temperature is 95 K. Although this low temperature inhibits very complex chemistry, it is believed that liquid ethane exists on the surface. It is hypothesized that methane is converted to ethane, acetylene, ethylene and hydrogen cyanide (when combined with hydrogen) through photochemical processes; this last molecule is a building block of amino acids. Titan does not have an intrinsic magnetic field and is bathed in Saturn's magnetosphere, being a source of hydrogen atoms in the wake created behind the satellite.

The list of Saturn's satellites has been increased from 11 to at ieast 17, with 3 satellites discovered by Voyager 1, and three others by Voyager 2.

The most interesting features on Saturn's satellites are: a huge impact crater (10 km deep and 130 km wide) having in its center a mountain almost as high as Mount Everest on Earth, found on Mimas; an even larger crater on Tethys occupying about one-third of its diameter, and a gigantic fracture covering three-fourth of Tethys' circumference; the irregular shape of Hyperion; the retrograde orbit of Phoebe which unlike all other of Saturn's satellites, excepts Hyperion, rotates on its axis.

Magnetosphere

in contrast to the magnetic fields 01 other planets, Saturn's field is almost aligned with its rotation poles.

An inner torus and an outer torus of the magnetosphere have been identified. The source of material for the inner torus is probably water ice originating from Dione and Tethys, whereas the thick plasma sheet forming the outer torus contains material originating from Saturn's ionosphere, Titan's atmosphere and the neutral hydrogen torus surrounding Titan.

The Uranus Voyager 2 Mission

Voyager 2 arrived at Uranus in January

1986. Before Voyager's visit to Uranus, the information known about the planet was very sketchy. The planet's rate of rotation could only be roughly estimated, and the evidence of a magnetic field was not conclusive. It was known that Uranus orbits the Sun tipped on its side with its five satellites and its rings being in a plane perpendicular to the ecliptic. The northern and southern polar regions are alternately facing the Sun during the planet's 84-year orbit.

Despite Uranus receiving only 1 /400th of the sunlight that falls on Earth, conclusive photographs" were obtained by linking the DSN antennas. These photographs yielded amazing new information.

Uranus' atmosphere

Uranus' clouds appear to be organized into latitudinal bands, similar to Jupiter and Saturn. At midlatitudes, winds having velocities of 40-160 m/see (to be compared to Earth's jet streams having velocities of 50 m/see), blow in the direction of the planet's rotation, just as on Earth, Jupiter and Saturn. At the equator, winds blow in the opposite direction with velocities of 100 m/see.

The chemical constituents of the atmosphere are hydrogen and helium, with the helium/hydrogen volumetric ratio being 15%. Traces of methane and acetylene, as well as other hydrocarbons exist in the atmosphere, and the blue-green color of Uranus is due to the methane in the upper atmosphere absorbing red light. Around the sunlit pole, a high layer of haze (smog) was observed. The sunlit hemisphere also radiates large amounts of ultraviolet light.

The average temperature on Uranus is 60 K, although in the upper atmosphere it increases to 150 K. Investigators found that below the troposphere (the lowest level of the atmosphere) the temperature is nearty uniform over the entire planet within 2-3 K.

The Rings

Uranus' rings seem to be very different from Jupiter's and Saturn's. The outermost ring (the ϵ) appears to be less than 150 m thick and composed of ice boulders of metric dimensions interspersed with a dilute distribution of fine dust. Incomplete rings were also identified, suggesting perhaps that they were debris of a broken satellite. This suggestion is reinforced by the finding that two small satellites straddle the ϵ ring. This may also lend credibility to the theory that rings have shepherding satellites which prevent the escape or collapse of the ring. This theory seem to be valid for the meter size particles, but not for the submeter particles which seems to fall through the planet's extended hydrogen atmosphere. Beside the known nine rings, two more rings were detected.

Satellites

Five satellites were known before the Voyager encounter and ten more were discovered during the mission.

The composition of the five larger satellites appears to be about 50°4 water ice, 20% carbon and nitrogen compounds and 30% rock, and thus be very similar to Saturn's satellites. Although the surfaces of all satellites appear to have a dark grey color, their geology seems to be quite different.

For example, Titania displays huge fault systems and canyons. Ariel seems to have the youngest surface, although it has fault valleys and apparently flows of icy materials. In contrast to the brightness of Ariel, Umbriel is dark, ancient and with large craters. Oberon is also ancient and cratered, having dark material at the bottom of many craters.

Miranda, the innermost satellite, has surprising patterns on its surface, with new and old terrain intermingled. Huge fault canyons, as deep as 20 km, alternate with terraced layers. It is thought that this strange surface is either the result of incomplete differentiation (upwelling of lighter material in limited areas) or that of reaggregation of material from an earlier impact.

Magnetosphere

Uranus' magnetific field is strong and skewed with its axis, tilted at a 60° angle with the axis of rotation. Because of its large offset from the center of the planet, the magnetic field on the “surface” varies with position, The origin of this magnetic field tilt is unknown.

Uranus has a magnetotail, and due to the combined effect of the tilt of the magnetic axis and the axis of rotation, the field lines in this magnetotail are wound into a corkscrew shape. Radiation belts of extreme intensity were detected. Radio emissions from Uranus shows that its period of rotation is about 17 hours and 14 minutes.

The Neptune Voyager 2 Mission

Neptune is the densest and the smallest of the four gas giant planets discussed here. Like other planets described here, it has no solid surface and is composed of a massive atmosphere whose composition is mainly hydrogen and helium.

Neptune is so far from the Sun that it takes 165 years to complete its orbit, and has not accomplished an entire orbit since its discovery.

Neptune’s atmosphere

Despite its large distance from the Sun, Neptune has a dynamic atmosphere despite receiving only 3% of the Jovian sunlight. Like Jupiter, it exhibits large dark spots, the largest one being the “Great Dark Spot” which is large enough for Earth to fit inside it. Compared to Jupiter’s Great Red Spot, this is also an anticyclonic feature but varies much more in size and shape. At the southern and northeastern boundaries of the Great Dark Spot, cirrus-type clouds, similar to lenticular clouds on Earth were observed.

Other circular cloud features move east-to-west around the planet with a shorter period than the Great Dark Spot. Most winds on Neptune blow in the retrograde direction which is east-west. Neptune has the record for being the most windy planet with winds blowing up to 2,400 km/hour near the Great Dark Spot.

Measurements showed that temperature varies with latitude, being warmer near the equator and at the south pole than at mid-latitudes. In the stratosphere, temperatures of 750 K were measured whereas at the 100 millibar pressure level, temperatures dropped to 55 K. Because of its enormous distance from the Sun, the heat in the stratosphere can be explained only by internal processes. It is thought that convection in the atmosphere causes compressional heating: gases rise at the mid-latitudes where they cool, then drift towards the pole and equator where they sink and become warmer.

Neptune appears blue in pictures because its atmosphere is rich in methane which absorbs light in the red region of the spectrum. Methane is the most important constituent of the atmosphere and cycles through various altitudes of Neptune as follows: High in the atmosphere methane is converted to ethane, acetylene and haze particles of complex polymers by the action of the ultraviolet radiation from the Sun. The haze particles sink to cooler regions of the stratosphere where they become ice particles. These ice particles sink further to the warmer troposphere where they evaporate back to gas, and the gases mix with hydrogen gas at high temperatures and pressures and regenerate methane. Warm methane rises again to the higher atmosphere restarting the process,

The Rings

Before Voyager 2 arrived at Neptune, Earth-based observations showed ring-arcs which did not go completely around the planet, thus defying the laws of physics. These arcs were thought to be the result of shepherding satellites.

During the Neptune encounter, high resolution photographs showed that the rings do go completely around the planet, but that the material in them is so fine and diffuse, that it escaped observations.

There seem to be four basic rings named: the Main Ring located in the outermost region and displaying clumps of material, a feature that puzzled investigators; the Inner Ring; the Inside Ring which is suspected to extend almost to the cloud tops; and the Plateau which consists of a diffuse sheet of fine material located just outside the Inner Ring, The largest proportion of fine material, which is about the size of smoke particles, is contained in the Plateau. Larger material is contained in the other rings.

The Satellites

Before the Voyager encounter, Neptune was known to have only two satellites - Triton and Nereid. Voyager discovered six new satellites.

Triton is a very interesting object in that it circles Neptune in a tilted, circular, retrograde orbit, and thus -- like Phoebe which orbits Saturn in a retrograde orbit -- is thought to be an object captured well after the formation of the solar system. Triton surprised investigators by exhibiting geyser-like eruptions of invisible nitrogen gas and dark dust particles which reach several kilometers into space. Triton's density of about 2,07 g/cm^3 implies that it contains more rock than its icy equivalents orbiting Saturn and Uranus. This rocky structure is hypothesized to have evolved from a previously liquid one, as tidal heating could have melted Triton during the time of its capture when its orbit was eccentric. Most of the present relief on Triton is thought to be formed of water ice because nitrogen and methane ice are too soft to form self-supporting structures. Given the fact that both nitrogen and methane become gas at less than 100 K, because of the low temperature on Triton, it is conceivable that most recent eruptions were due to nitrogen and methane.

Triton seems to have an extremely thin, but extensive atmosphere containing minute nitrogen ice particles. At the surface, the pressure is about 14 microbars while the temperature is 38 K, thus being the coldest surface of any studied body in the solar system. The temperature increases to 95 K at 800 km above the surface. Polar caps and wind streaks have also been identified on Triton.

From Earth-based studies of Pluto, it seems that Triton is Pluto's closest model in terms of size, density, temperature and chemical composition.

Nereid stands out as having the most eccentric orbit in the solar system.

The six other satellites are all very dark, irregularly shaped and their orbit is close to Neptune's equatorial plane.

The magnetosphere

In order to have a magnetic field, investigators believe that a planet must have an interior region occupied by a liquid which is electrically conducting and that there must be an energy source which drives a continuous motion within the liquid.

Neptune's magnetic field is unusual in that it is tilted 47° from its axis of rotation and is offset at least 0.55 radii from its center. Thus, in certain portions of the planet the electric currents must be rather close to the "surface". Due to the combined effect of the tilt of the rotation axis and the unusual orientation of the magnetic field, major changes in the magnetic field are observed as Neptune rotates in the solar wind.

Neptune's magnetic field polarity is the same as those of Jupiter and Saturn and opposite to that of Earth.

Radio waves generated by the magnetic field allowed the determination of Neptune's interior rotation rate which is 16 hours and minutes,

Auroras were also detected on Neptune, however because of Neptune's complex magnetic field, they are not restricted to the magnetic poles and instead occur over wide regions of the planet.

The Venus **Magellan** Mission

Magellan is a spacecraft which was launched in May 1989, it has an unique science instrument -- the synthetic aperture radar -- which can penetrate through Venus' thick carbon dioxide clouds and image its surface.

Venus is similar to Earth in density and size, but this is where the similarities end. Venus' pressure and temperature are extremely high, its atmosphere is 97% carbon dioxide and contains only minute amounts of water. The upper clouds curtain sulfuric acid.

Venus has no satellites and no magnetic field. It rotates on its axis very slowly (with a period of 243 Earth days) and in a retrograde direction.

Radar scans have detected an enormous mountain on Venus which could be a volcano. Large land masses seem to rise with very steep slopes above lowlands. It is yet uncertain if Venus has any tectonic processes.

To investigators, Venus is an extreme example of the greenhouse effect with large amounts of heat absorbed from the Sun and trapped by the carbon dioxide.

Magellan is still mapping Venus, and its mission could be extended beyond its initially allocated time.

The Role of Spray Science Within the Space Program

When one thinks of the space program, the tendency is to focus on the new facts discovered during the missions and take for granted that spacecraft have been launched into orbit. Indeed, satellites have been launched into orbit since the 1950's and it is generally expected that this is a mature technology.

The reality is far from this picture. Investigators and technologists have been fighting rocket combustion instabilities for decades, and so far all the solutions to this problem have been found through trial and error experiments, and for limited operation regimes. In fact it is not known whether these experimentally determined operational regimes are on the edge of highly unstable operating regimes, so that small perturbations might switch the operation regime to an unstable one. There is basically no fundamental understanding of the evaporation, mixing, ignition and combustion in a liquid propellant rocket environment.

The basic physics associated with single drop evaporation and combustion in a quiescent environment at low pressure has been well understood since the 1950's. During the last twenty years progress has been made in the understanding of the physics of isolated drop evaporation in convective flows, both for single and multicomponent fuel drops. The difference between the behavior of multidrop systems where interactions between drops are important, and the behavior of individual drops has also been studied, and the requirements of the modeling of sprays by subgrid modeling have been identified. There are many investigators who participated in these studies, and rather than quoting a few and omitting many, it is felt here that it is better not to make reference to individual studies and instead it is more beneficial to present the state of the art.

Another aspect that has been addressed is that of the spray polydispersity, that is, the fact that drops in a spray have a variety of sizes and are spatially distributed in a nonuniform way. This feature of the sprays is very important because the small drops initiate ignition, whereas the larger drops determine spray penetration into the injection chamber; experimentalists know well that it is very difficult to ignite a monodisperse spray. A particular lead in studying polydisperse sprays was taken at the Technion.

Issues that need further investigation are those of the high number density regions, the polydisperse aspect, microscale dropdispersion, interaction between drops and turbulence and supercritical effects.

All these issues must be addressed if one is to improve rocket flight safety and equipment longevity, and thus be able to successfully launch future space missions.

Summary and Conclusions

It is by now well recognized that the discoveries of the Space Program have not only satisfied our curiosity about the solar system and the Universe, but also that they have tremendously increased our understanding about Earth and the environment in which we live,

The Voyager missions are continuing as both spacecraft are heading out of the solar system. Voyager 1 is climbing above the ecliptic plane, and Voyager 2 is traveling below that plane. Both spacecraft will investigate the Solar poles and the heliopause which is the boundary between the solar wind and interstellar space. It is anticipated that if both Voyagers remain operational, they could transmit data for another 25-30 years. These data will provide valuable information about magnetic fields and particles in interplanetary and interstellar space

Magellan it is still orbiting Venus and mapping the planet, and Galileo is expected at Jupiter in 1995.

The Mars Observer was launched in September 1992 and its mission is to study the surface, atmosphere, interior and magnetic field of Mars for an entire Martian year. Of particular interest is the study of the role that water might have played on Mars. Both Mariner and Viking missions found geological evidence that liquid has flowed on Mars before it became arid. Other issues to be determined are topography, gravitational field, magnetic field, chemical composition of the surface and the atmosphere, and temperature of the atmosphere. Since it will take 11 months for the spacecraft to arrive to Mars, it is premature to comment on its accomplishments.

The current NASA philosophy is to concentrate on cheaper missions -- up to $150 million per mission -- in the future. These cheaper missions will be more focused on a single aspect and therefore will have a more restrictive scope, but returns from the studies will come faster. Thus, it is expected that since one would be able to have many more missions, they will provide increased flexibility.

Space exploration has opened for us a wider window over the Universe and it is anticipated that the forthcoming space missions will continue to surprise our imagination and challenge our minds.

Acknowledgment

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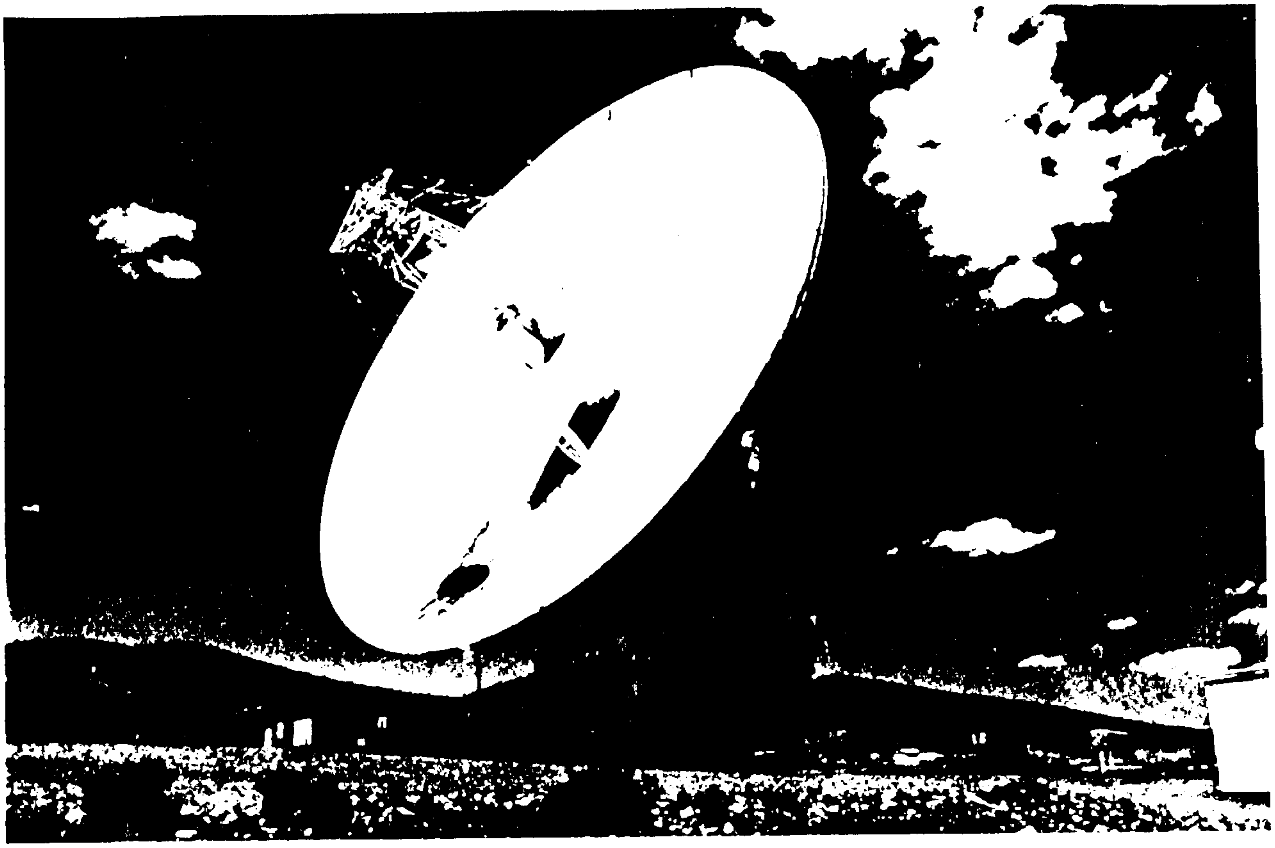


Figure 1. Goldstone; 64 m Antenna.

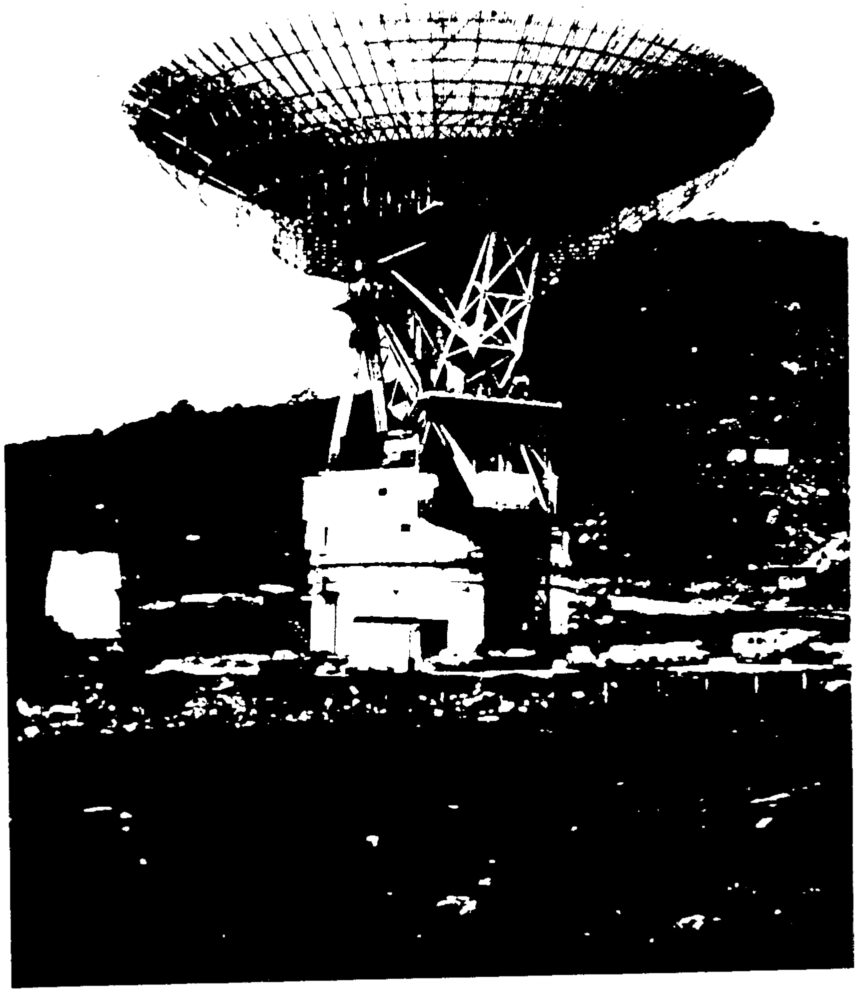


Figure 2 Australia; 64 m Antenna

Figure 3 Spain; 64 Antenna

Figure 4. 10. A massive volcano can be seen at the horizon.
Debris are ejected to a height of 160 km.

Figure 5. Closeup of Jupiter's cloud movement.

Figure 6. Jupiter from equator to south polar latitudes near the Great Red Spot,

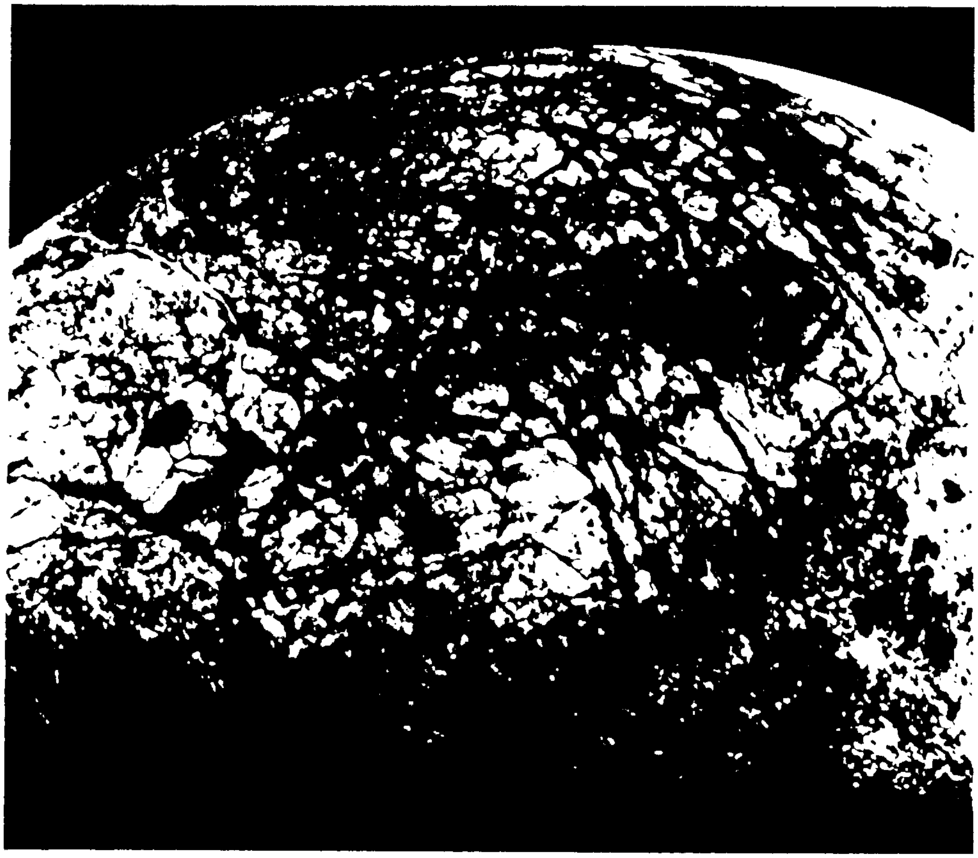


Figure 7. Closeup of Europa from 240,000 km.

Figure 8. Ganymede from 242,880 km.

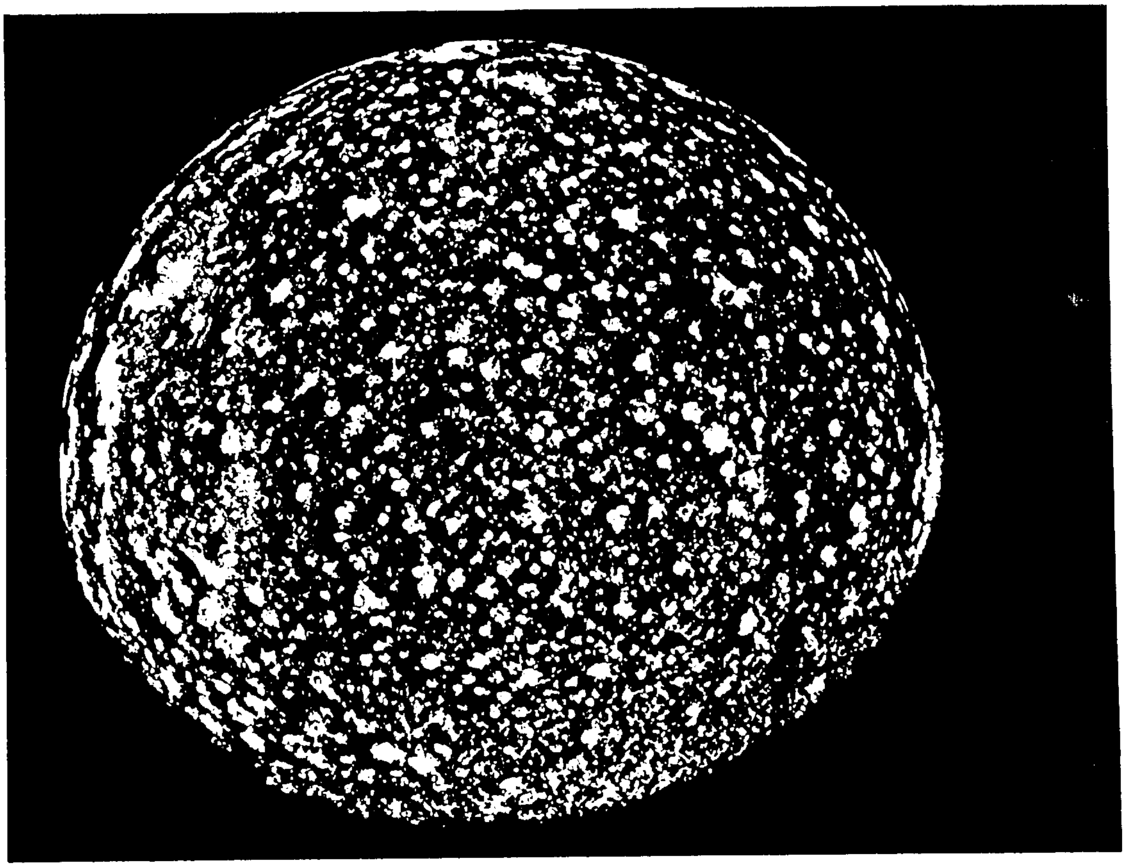
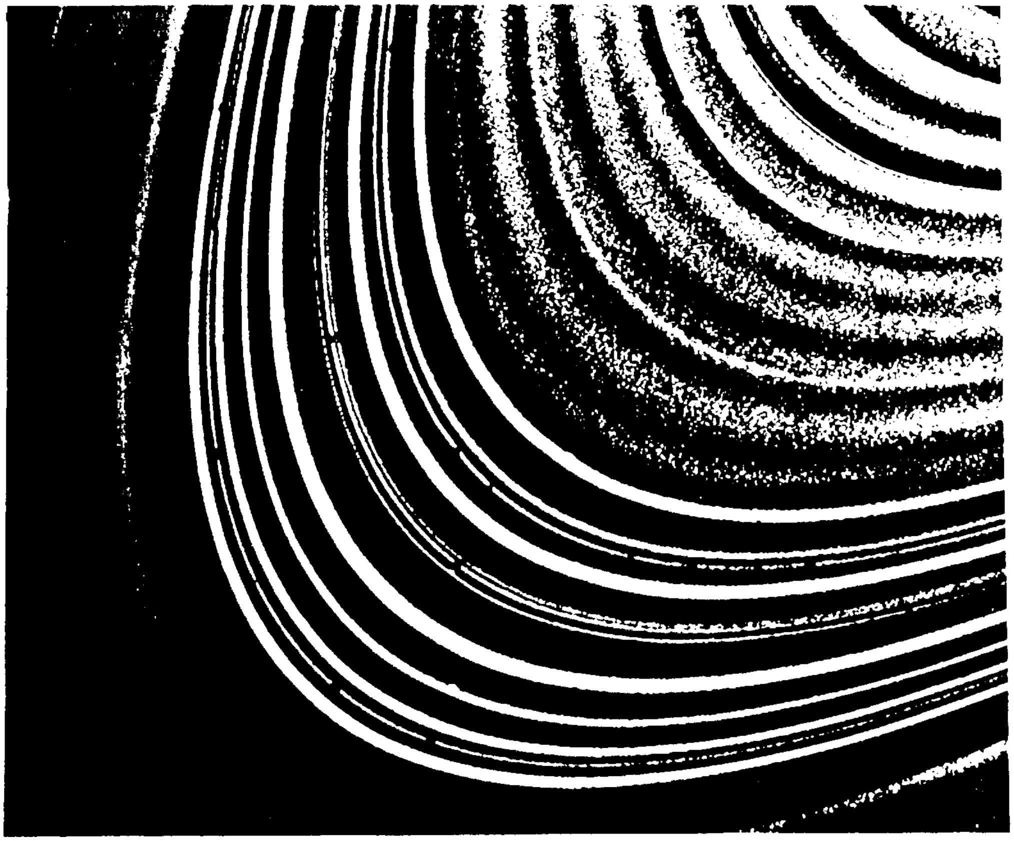


Figure 9. Photomosaic of Callisto from 9 frames, obtained at 392,000 km.

Figure 10. Jupiter's ring by sunlight coming from behind.

Figure 11. Saturn's Northern hemisphere.



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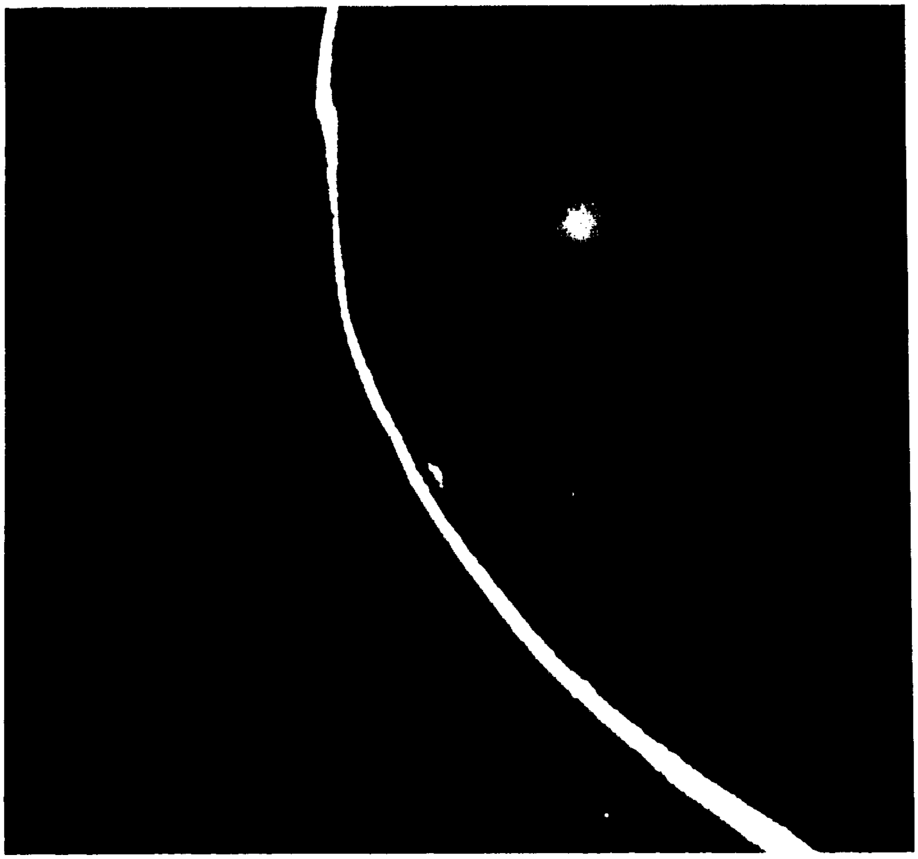

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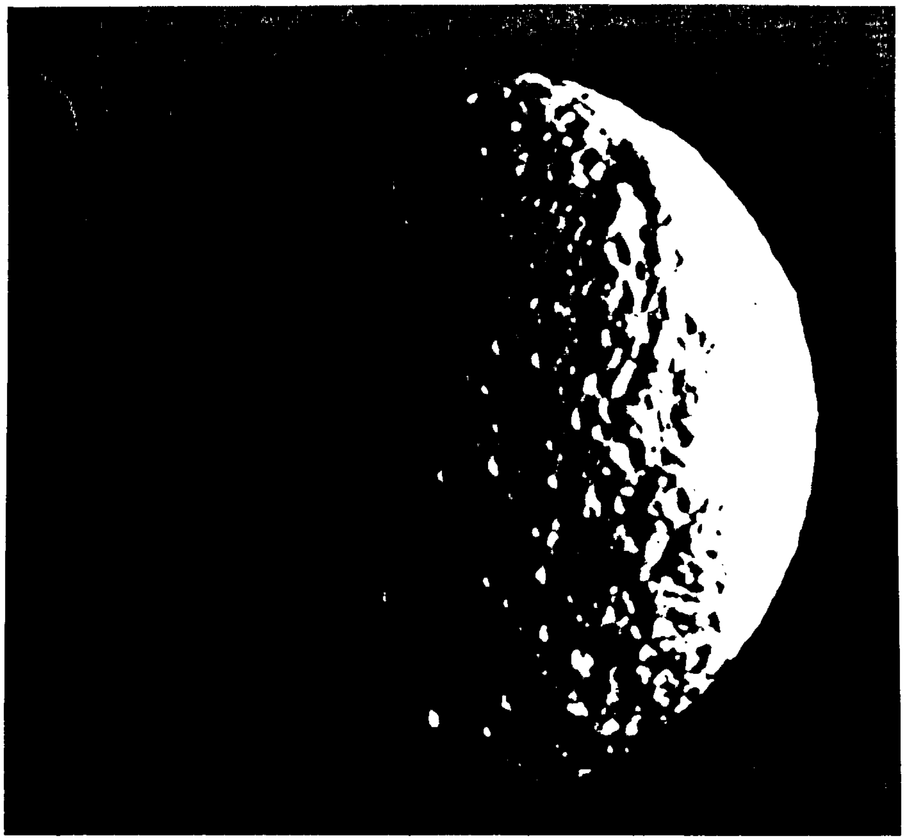

Figure 14. Mimas' heavily cratered surface. Range 129,000 km.

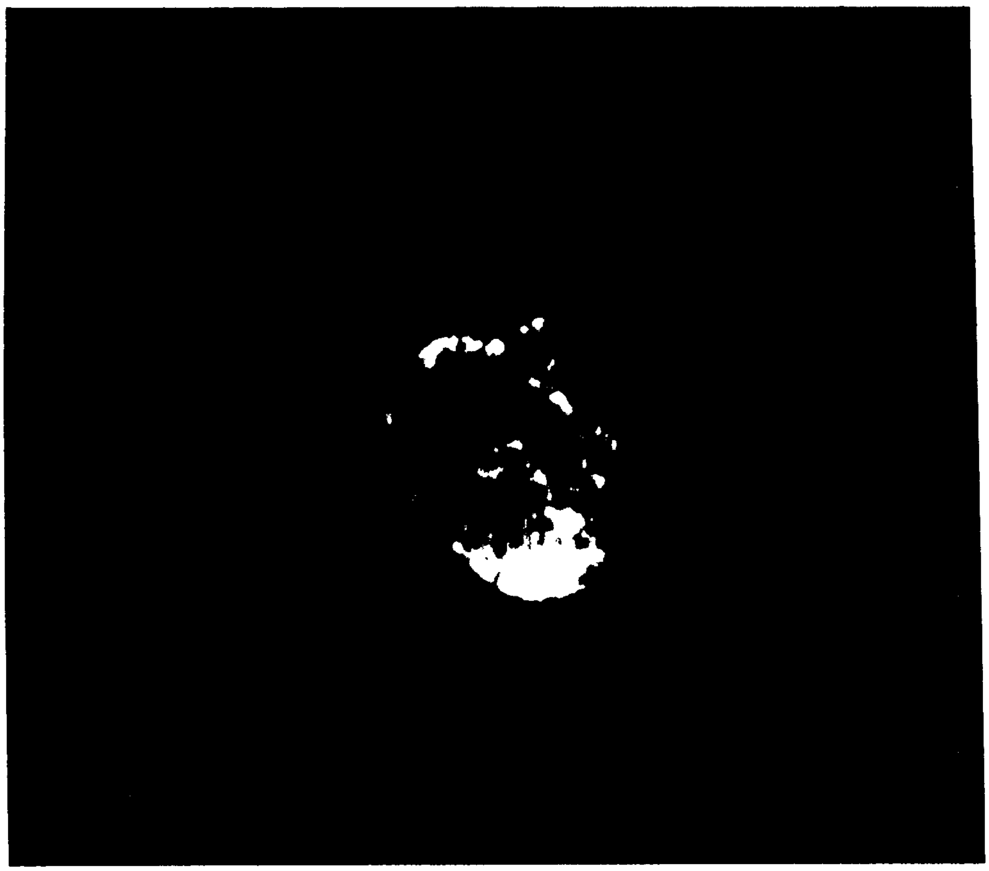

Figure 15. Hyperion: An irregular-shaped object, 376 km across.

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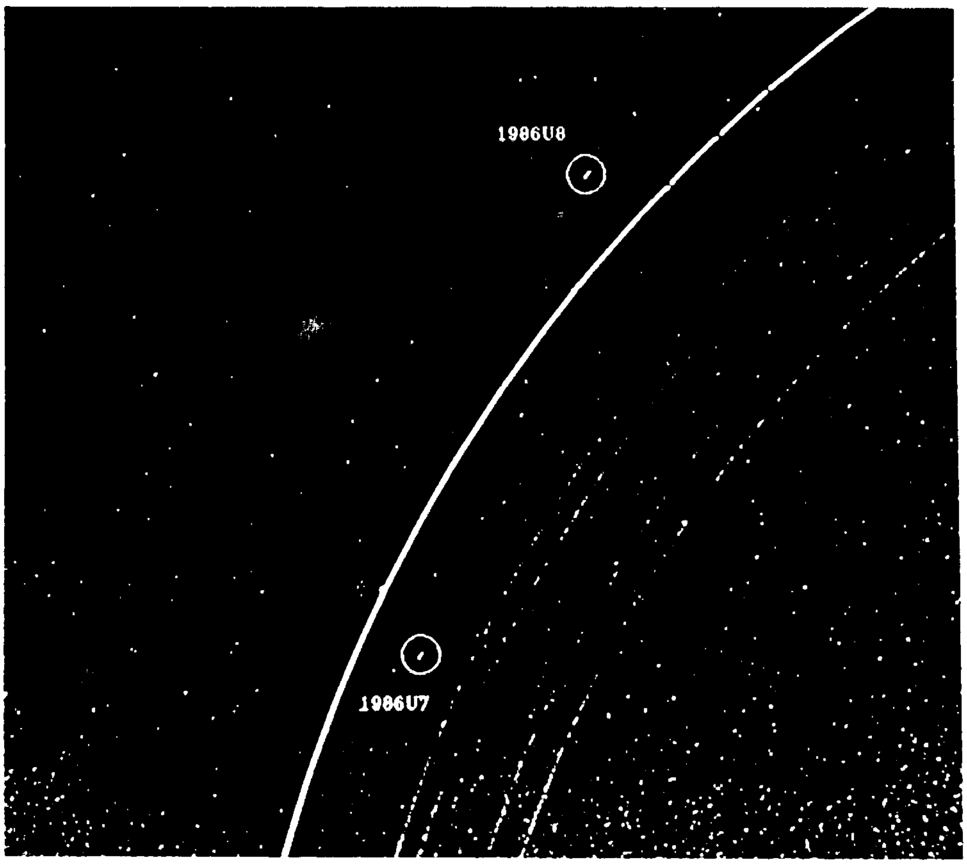

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Figure 18. High-resolution terrain photograph of Miranda.

Figure 19. A view of Neptune with its Great Dark Spot.

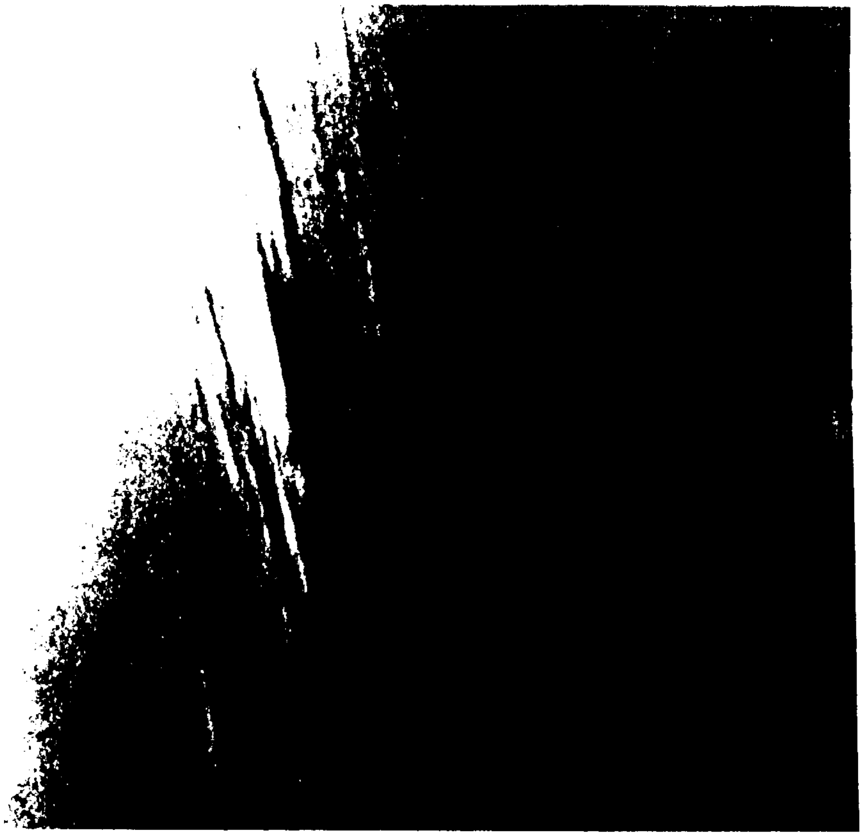

Figure 20. Lenticular, high altitude clouds on Neptune.

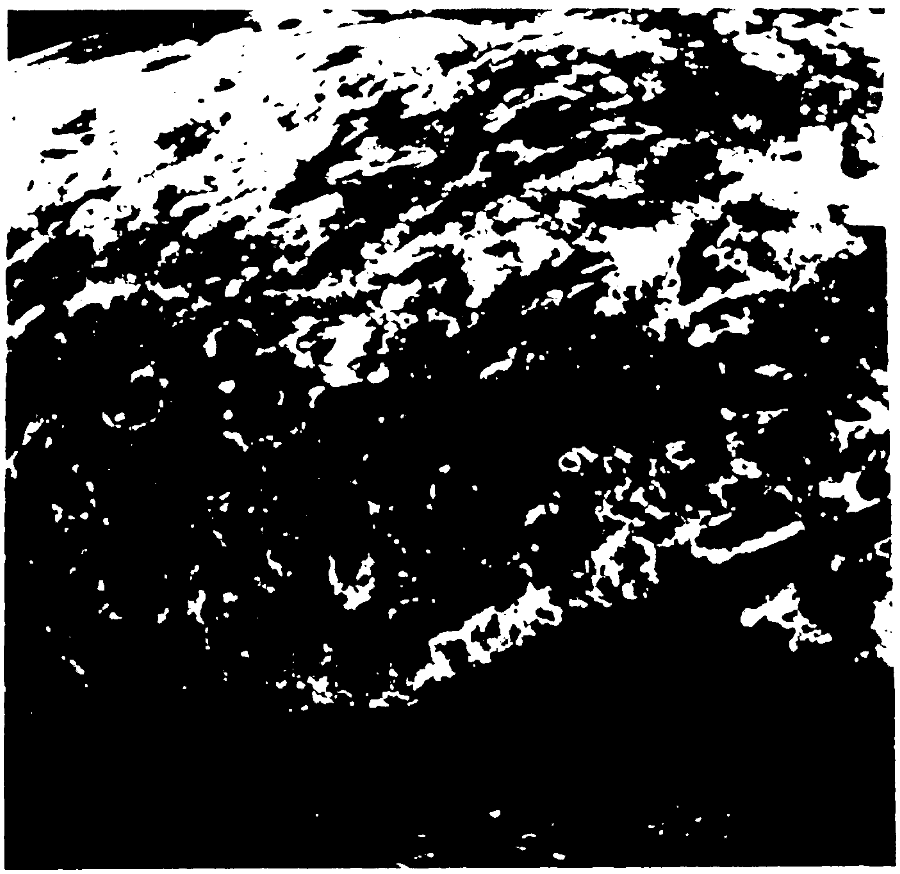

Figure 21. Volcanic activity in Triton.

Figure 22. Computer-generated prospective view of one of Triton's caldera-like depressions.

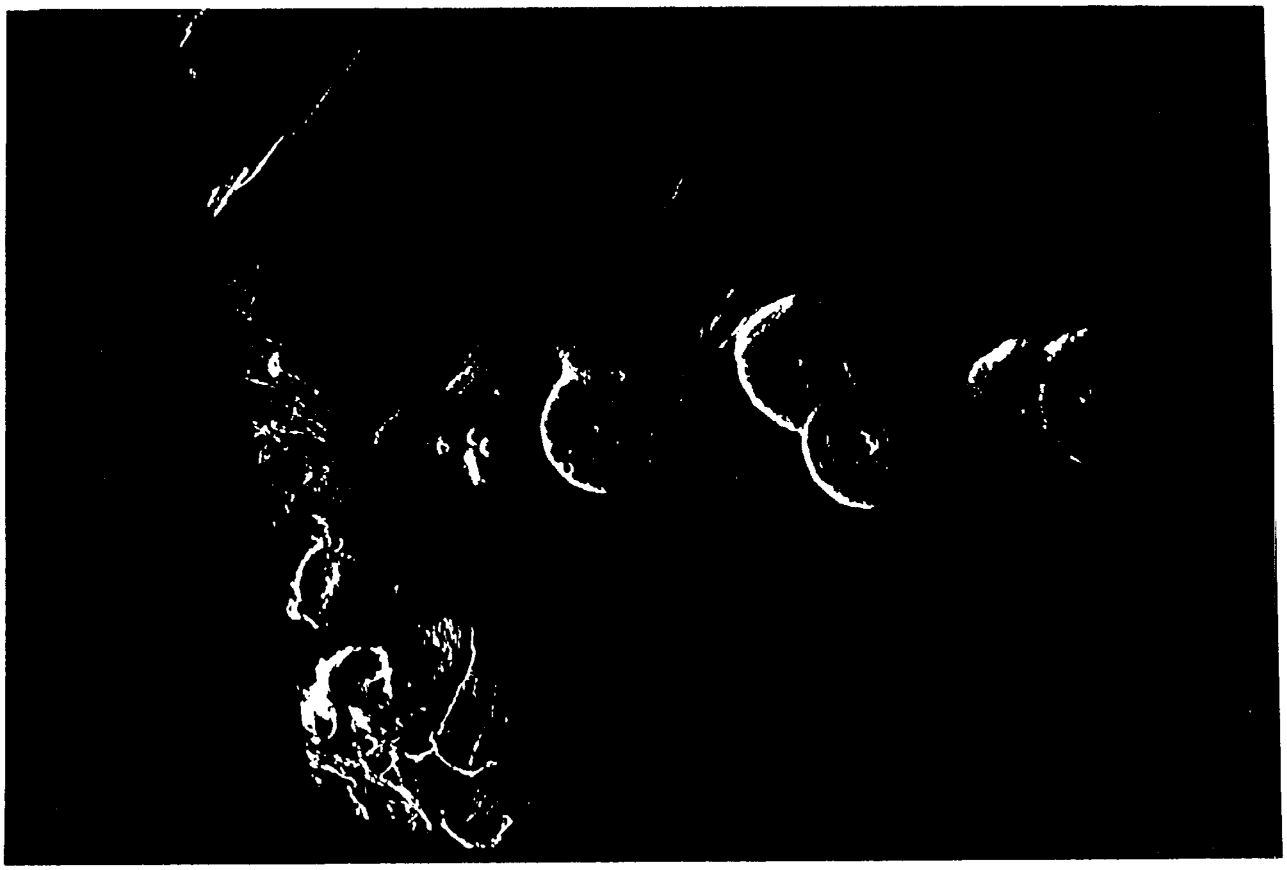

Figure 23. "Pancake" volcanic domes on Venus.

Figure 24. Impact crater Aurelia on Venus.

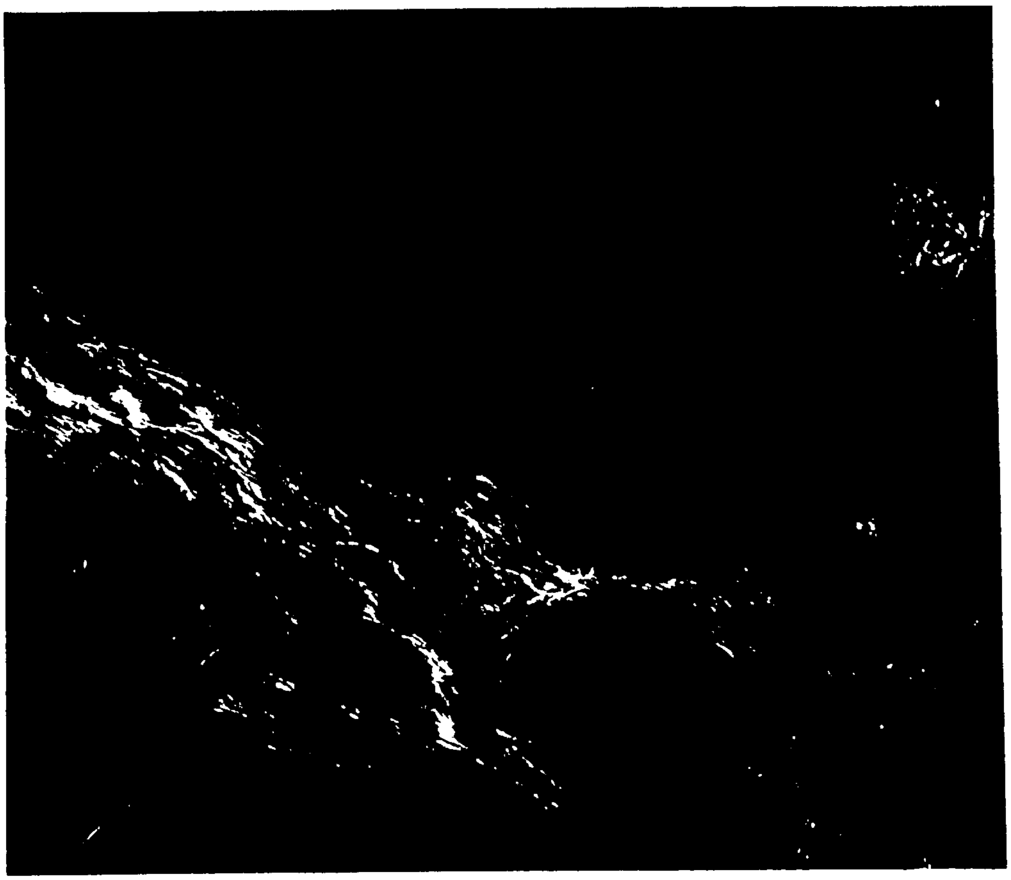

Figure 25. Ridge belts in Lavinia region on Venus.

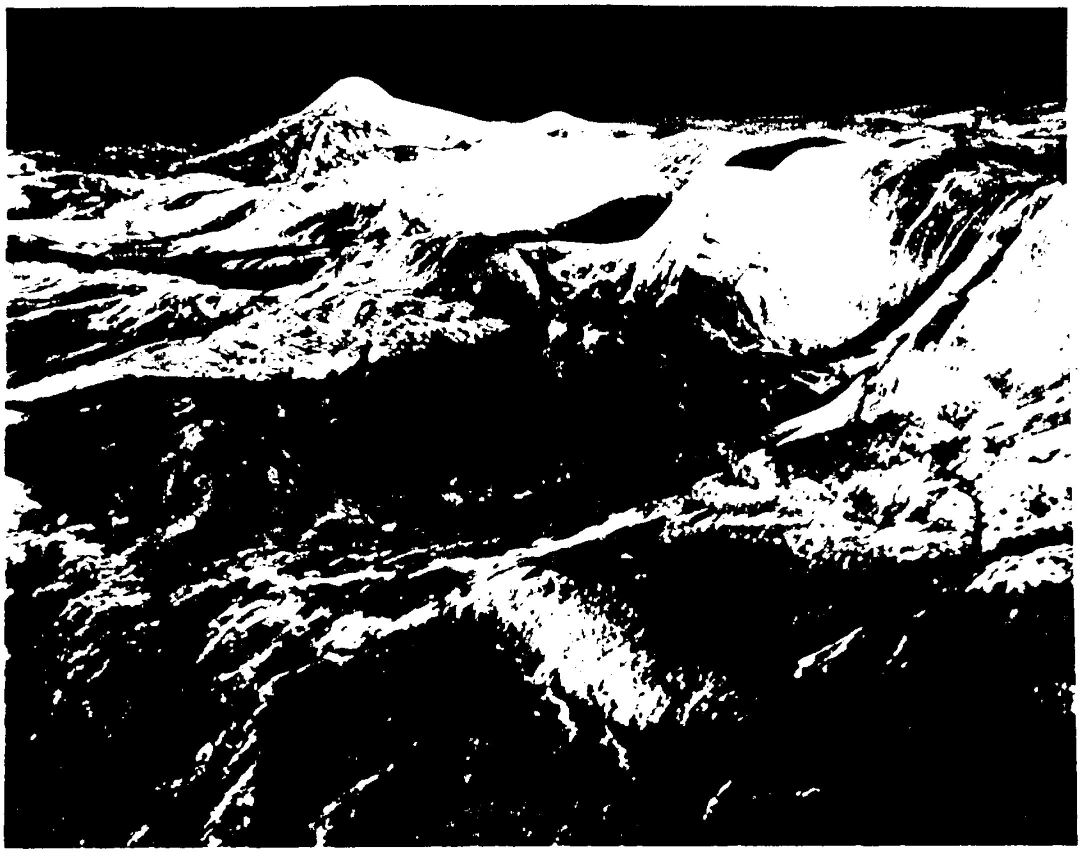

Figure 26. Perspective of the south-east rim of Lakshimi planum. Danu Montes rises 1.5 km above the plateau and can be seen in the upper center.