RINGS AND ICE: VOYAGER 2 AT SATURN

by

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The objectives of NASA's Voyager 2 mission were adapted to pursue the many startling findings of Voyager 1's encounter with Saturn last November (see EPISODES 1980, No. 4, p. 9-11). The harvest of scientific data reaped from this latest voyage through the Saturnian system will challenge the understanding of planetary geologists and meteorologists for years to come.

Background

On August 25, 1981, Voyager 2 took the closest look yet at Saturn, some of its rings and its satellites. Although Voyager 1 had passed through this region of space in November of 1980, Voyager 2 came 23 000 km closer to the cloudtops of the ringed planet, and its on-board cameras produced 50% better resolution in the photographs returned to Earth. Scientists who gathered in Pasadena, California, U.S.A. at the Jet Propulsion Laboratory (JPL) which manages the Voyager project for NASA, represented universities, research laboratories, and governments in the U.S.A., U.K., France, and the F.R.G.

The results of the Voyager 1 encounter had raised many questions about the Saturnian system, including its mechanisms for ring rotation and formation, the nature of Saturn's satellites, and its atmospheric activity. Voyager 2 was therefore extensively re-programmed to allow a more focused observation of certain parts of the Saturnian system.

Rings Within Rings

A major point of interest for the Voyager 2 encounter was the ring system. Before Voyager 1 reached Saturn, scientists believed that the rings could be divided into a maximum of 5 or 6 zones. Voyager 1 images had revealed that there may be up to 1 000 individual rings orbiting around Saturn. The Voyager 2 results have now caused the estimate to be changed once again: the rings and ringlets are believed by some to number "in the order of thousands" (Fig. 1), although the precise number will be refined as the results of a stellar occultation experiment onboard Voyager 2 are analyzed. The experiment measured the intensity of starlight as the spacecraft moved past the rings, recording the density of material between the detector and the star. Preliminary results indicate that the rings may only be about 200 m thick.

A sequence of photographs has been compiled of the spoke-like features observed in the rings as they emerge from

Figure 1. This Voyager 2 photograph of the lit face of Saturn's B-ring was obtained on August 25 from a distance of 743 000 km. It covers a range of about 6 000 km and shows the ring structure broken up into about 10 times more ringlets than previously suspected. The narrowest features here are about 15 km wide. Variations in brightness are due to a combination of differences in ring particle number density and light scattering properties. The B-ring is the most opaque of Saturn's rings; the highest resolution Voyager 1 observations were of its unlit face, where little detail is visible. (All photos courtesy Jet Propulsion Laboratory)

behind the planet. A time-lapse movie constructed from these frames should aid interpretation of the origin and nature of these features. Photographs of the ring plane, taken "edge-on" as the spacecraft crossed it immediately after closest encounter, should also help to resolve some of the questions about the rotation mechanisms of the rings.

The mechanism by which these rings are divided into ringlets is still a mystery. Many of the Voyager 2 photographs were intended to look for "moonlets" - tiny satellites that sweep up material in the narrow gaps between the ringlets, clearing the bands of their material. The search for these new satellites has not been productive, however, and the Voyager imaging team is now looking elsewhere for explanations of how the rings are formed. Rather than being concentric circles, the rings appear to spiral outward, not unlike grooves in a phonograph record.

Winds and Weather

The meteorology of Saturn as observed by Voyager 2 was far more complex than previously imagined. The planet's thick atmosphere was much more active during this second encounter and camera resolution was better (Fig. 2). Measured wind speeds near the equator of Saturn were up to 500 m/sec., while bands of high-speed easterlies were identified at 40, 58, and 68 degrees north latitude. A fascinating atmospheric phenomenon observed by Voyager 2 was a vortex separation in which eddies were produced by the separation of these easterly winds. The development of these circulating storm systems, on a scale similar to that of hurricanes on Earth, has been recorded on a series of sequential photographs.

Figure 2. The extensive ribbonlike cloud structure in Saturn's atmosphere is visible in this Voyager 2 green-filter photograph, obtained on August 23 from a range of 2.5 million km. Some scientists have interpreted the ribbon to be a large-scale atmospheric wave; it is believed to lie in a rapid eastward-moving jetstream. The presence of vortices adjacent to the ribbon itself will help scientists understand the relationship between such structures and the strong jetstreams present in Saturn's atmosphere. The smallest features visible in this photograph measure about 50 km across.

Another discovery was the lack of correlation between the zonal winds and the dark and light bands around the planet. Jetstreams in the northern hemisphere of Saturn appear to be analogs to jetstreams on Earth. Dr. Garry Hunt, meteorologist at University College, London, U.K., has pointed out that space explorations such as those conducted by Voyager 1 and 2, can be justified on the basis of meteorological aspects alone: the atmospheric activity observed by Voyager 2 will further our understanding of terrestrial atmospheric processes as well.

Icy Satellites

Voyager 2 revealed new information about the Saturnian satellites. The distribution of water in the Saturn system differs from that in Jupiter's. Most of Saturn's inner satellites appear to be predominantly water ice; Jupiter's inner moons, however, are too hot to contain water, and therefore only the outer, colder satellites are ice rich.

In its tour of the Saturnian system, Voyager 1 had made close approaches to Titan, Mimas, Dione, and Rhea. While Voyager 2's primary target was the ring system, it also took closer looks at several other satellites: Enceladus, Tethys, Hyperion, and Iapetus. Voyager 2 did not come as close to Titan, the largest of Saturn's moons, as Voyager 1 had, but it did produce some colour photographs (reconstructed from three separate images taken with coloured filters) clearly showing the orange clouds and blue haze layer, the colours being a product of particle scattering in Titan's atmosphere. Knowledge of the nitrogen-rich atmosphere of Titan will also be a helpful addition to studies of atmospheric evolution.

Enceladus proved to be the celebrity of the Voyager 2 encounter (Fig. 3). To Voyager 1, this 480 km in diameter

Figure 3. The surface of Enceladus is seen in this closeup view obtained on August 25, when Voyager 2 was 112 000 km from the satellite. Enceladus' north pole is toward the bottom right; the moon bears a striking resemblance to Ganymede, the largest Galilean satellite of Jupiter. Moderately cratered areas have been transected by strips of younger grooved terrain (the light cratering indicates it must be relatively young). This more recently formed terrain has consumed portions of craters such as those near the bottom center of the picture. This suggests that Enceladus has experienced internal melting even though it is only about 490 km in diameter. The grooves and linear features indicate that the satellite has been subjected to considerable crustal deformation as a result of this internal melting. The largest crater visible here is about 35 km across.

satellite appeared smooth and brighter than the other satellites. This smooth appearance represents a fairly fresh, icy surface. Enceladus has the least amount of cratering of any of Saturn's satellites, indicating that it has experienced continuous geological activity and "re-surfacing" over the last several billion years. Its surface appears similar to that of Jupiter's moon Ganymede, even though the Galilean satellite has nearly a thousand times more mass. Scientists suspect that Enceladus may be tidally locked with the moon Dione (studied by Voyager 1), causing tidal pumping. A similar tidal lock between Io and Jupiter seems to cause the active volcanism on that satellite.

The icy Enceladus may have melted and refrozen many times in its history. Fracture systems on its surface suggest that it may also have extensive tectonic activity, with both rigid and plastic plate motion. Imaging team geologists are continuing to unravel the evolution of this satellite.

Tethys, 1050 km in diameter, also held a few surprises. The canyon on Tethys, first seen by Voyager 1, was revealed by Voyager 2 to extend across nearly 70% of the planet's surface (Fig. 4). A giant crater, 400 km across, has a diameter greater than that of the moon Mimas, whose huge impact crater was photographed by Voyager 1. The cratering record on Tethys is well preserved. Linear terrain cuts some of the old craters into two parts, segmenting the older, cratered terrain. The variety of terrain types and apparent ages on Tethys gives it a surficial appearance similar to some of the terrestrial planets. The resurfacing and tectonics are evidence of internal activity, but whether the process indicates convective activity or expansion by freezing is still being studied.

The photographs of the satellite Hyperion (not studied by Voyager 1) also took the imaging team by surprise (Fig. 5). The population of craters on its surface suggests that the

latter is ancient, while its 30% albedo indicates the presence of water ice as a frosty covering. Its irregular shape (variously described as a peanut, a potato, or a hamburger) was previously believed to be spherical. Equally astonishing

Figure 4. Voyager 2 obtained this image of Tethys on August 25, when the spacecraft was 594 000 km from this satellite of Saturn. The photograph was compiled from images taken through the violet, clear and green filters of Voyager's narrow-angle camera. Tethys shows two distinct types of terrain - bright, densely cratered regions, and relatively dark, lightly cratered planes that extend in a broad belt across the satellite. The densely cratered terrain is believed to be part of the ancient crust of the satellite; the lightly cratered planes are thought to have been formed later by internal processes. A trough runs parallel to the terminator (the day-night boundary, seen at right); it is an extension of the huge canyon system which extends nearly two-thirds the distance around Tethys.

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Figure 5. These three views of Hyperion were obtained (from top) on the morning of August 23 from a range of 1.2 million km, on the morning of the 24th from 700 000 km and at noon on the 24th from 500 000 km. Together, they show the changing aspect of the satellite as Voyager moved in for closer views. Hyperion, roughly 360 km by 210 km, is probably not in a gravitationally stable position. Its surface is pock-marked with many meteorite-impact craters. It is possible that one of these impacts jostled Hyperion out of position and that the satellite will swing back gradually.

was the orientation of the satellite as it orbits around Saturn: rather than having its long axis in the orbital plane, it is angled at approximately 45 degrees to its orbit. This deviation suggests that the moon may have been hit so strongly by a meteorite that it was moved into a new orbit.

Voyager 2 data revealed that Iapetus (diameter = 1440 km) has a density of about 1.1, indicating that it is an ice ball containing less than 20% rock (Fig. 6). Part of the surface is covered with dark red material that may be carbonaceous; the Voyager imaging team is investigating both internal and external activity as possible sources of this low-albedo area.

Problems and Prospects

Approximately one hour after Voyager 2's closest approach to Saturn (while it was hidden from Earth on Saturn's darkside), a problem developed in the scan platform on which four of the 11 science experiments were mounted, including the cameras. The mechanism that rotates the platform in one of two possible directions jammed, leaving the cameras pointing into and photographing deep space. With a one-way travel time of approximately 1.5 hours between Earth and Saturn, the process of locating the problem and correcting it proved time consuming and tedious. Some of the planned post-encounter sequences were missed, although all of the major scientific objectives of the mission had already been completed. As Project Scientist Dr. Ed Stone of the California Institute of Technology pointed out, "We're just glad it didn't happen an hour or two earlier."

Although some quantity of data had been lost, the quality of the data returned is very high. In discussing Enceladus, Dr. Larry Soderblom (U.S. Geological Survey, Flagstaff, Arizona, U.S.A.) expressed a case in point. Its intricate surface, he said, "might make it the most peculiar object in the solar system." The satellite was imaged once at high resolution, but two other planned sets of high-resolution mosaics were lost during the scan-platform malfunction. Tethys was also covered by only one of two planned high-resolution sequences. All of the other image sequences of satellites were completed, including Phoebe, which was scheduled for observation 10 days after the closest encounter with Saturn.

Despite the problems, over 16 000 images were taken of the ringed planets. At present, Voyager 2 is expected to be on time for its rendezvous with Uranus on January 24, 1986. After the spacecraft has made the 1.5×10^9 km journey to Saturn, arriving within 3 seconds and 50 km of the scheduled target, there is good reason to expect that the additional 2.84×10^9 km to Uranus will be an easy trip.

Meanwhile, planetary scientists will be occupied trying to unravel the data that has already been collected. As Dr. Stone pointed out immediately after Voyager 2's closest approach to Saturn, "We have increased our knowledge; now we need to increase our understanding." This will take many years.

Figure 6. Voyager 2 made its closest approach to Iapetus, the outermost of Saturn's large satellites, on August 22. The spacecraft was 1.1 million km from Iapetus; the camera resolution was about 21 km. This view, which is lit from above, primarily shows the heavily cratered northern hemisphere toward the bright trailing side of the satellite. The north pole is near the large central-peak crater seen partly in the shadow at the top of the image. Iapetus is noteworthy for the very dark material (lower and right-hand parts of this frame) that apparently covers the ice crust of the satellite mostly at its leading hemisphere. This dark material is red and reflects only about 5% of the incident sunlight; it may be of either external or internal origin. Study of its relationship with the underlying topography - for example, near the large crater at the border of the dark material - may help to resolve this mystery.

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