Saturn Redux: The Voyager 2 Mission

Despite a sticky camera platform, the encounter achieved most of its scientific goals; next stop, Uranus

Pasadena, California. Once again, the video monitors glowed with the haunting Voyager images of Saturn: the pale, cloudy, turbulent sphere of the planet itself, the icy moons, and the translucent, spun-glass rings.

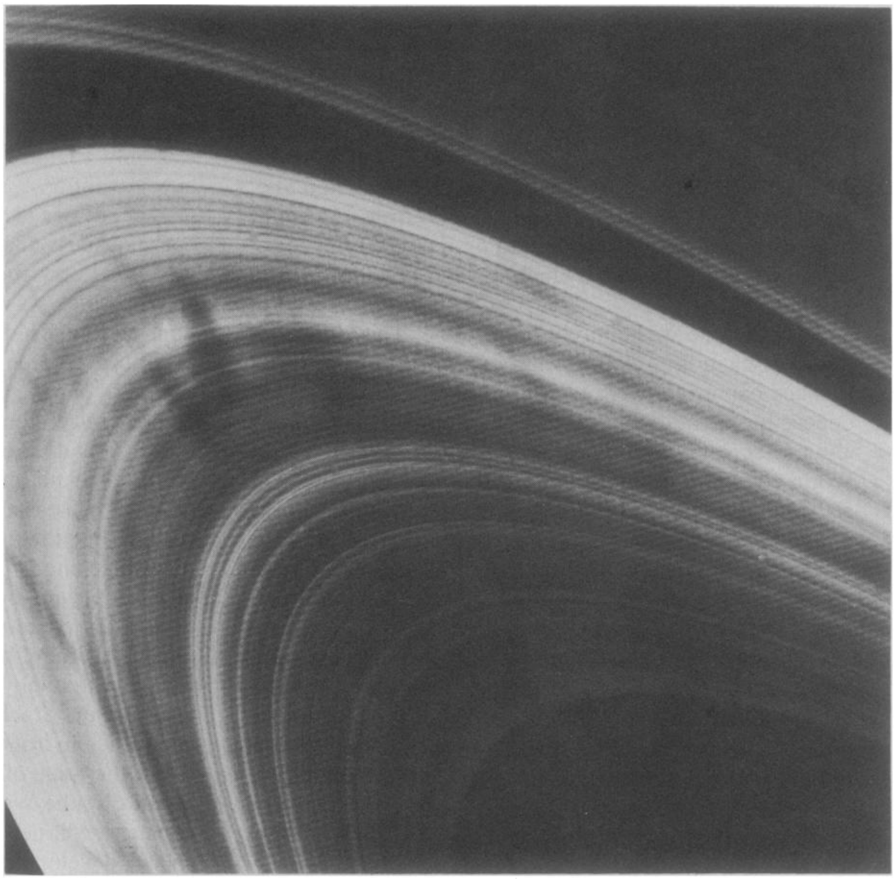
And once again the watchers gathered at the Jet Propulsion Laboratory here: 280 Voyager engineers who operated and tracked the spacecraft; 120 mission scientists, who struggled to make sense of the data pouring down from Saturn at 44,800 bits of information per second; and hundreds of VIP's, NASA officials, reporters, television crewmen, and science fiction writers, who stared at the images on the video monitors in unabashed wonder.

Jet Propulsion Laboratory was awash with an ebullient sense of reunion at the Voyager 2 encounter with the planet. This was the fourth time around, after all: both Voyager 1 and 2 had flown by Jupiter in 1979, and Voyager 1 passed Saturn just last November.

But there was also a poignant sense, among scientists and reporters alike, that this might be the Last Picture Show. The Voyager program was originally intended as a two-spacecraft exploration of Jupiter and Saturn only; Voyager 2 was completing that mission. True, plans have been revised to send it on to Uranus in 1986 and to Neptune in 1989. But Voyager 2 has already been in space for 4 years. Its primary radio receiver failed shortly after launch in 1977, and its backup receiver is ailing. (It has trouble locking onto signals from Earth; command signals have to be exquisitely tuned from this end.) Uranus and Neptune are billions of miles away and years in the future. Mission planner Charles E. Kohlhase calculated the odds on a successful Uranus encounter at no better than 2 out of 3.

It was in the context of Uranus that the failure of Voyager 2's scan platform loomed not just as a disappointment for Saturn-watchers, but as a near-disaster.

It happened shortly after closest approach to Saturn on the night of 25 August, when the trajectory to Uranus took Voyager 2 out of sight behind the planet and through the debris-strewn plane of the rings at some 13 kilometers per second.



Ringlets and gaplets and spokelets and . . .

This high resolution photo of the rings shows the multitude of ringlets and the baffling "spokes." The sharp and narrow appearance of the spokes suggests a short formation time. But other than a general suspicion that electromagnetic forces are at work, scientists are at a loss to explain them.

The reemergence of the spacecraft, right on time at 12:01 a.m. PDT on 26 August, set the Jet Propulsion Laboratory control rooms ringing with the sound of cheers, applause, and the pop of champagne corks. Yet, within half an hour the mood had cooled again to somber concern, as it became apparent that somewhere during the passage behind Saturn, the spacecraft's vital scan platform, bearing its infrared and ultraviolet sensors, its photopolarimeter and its wide- and narrow-angle cameras, had become stuck.

For most, the first anguished response to the news was, "What about Uranus?" Happily, as it turned out, the Uranus encounter promised to be just fine. Slow, careful experimentation with the spacecraft's high-torque motor soon began to loosen the platform, and by week's end the system was moving freely. In fact, mission planners decided to allow its unrestricted use during the 4 September closest approach to Saturn's outermost Satellite Phoebe. (Imagery of this dark little object should be particularly interesting. Its retrograde orbit indicates that it formed in some far-distant part of the solar system and only then was captured by Saturn.)

Deputy Voyager project manager Richard P. Laeser said that the platform had been behaving as if something were stuck in the gears—something which has presumably worked its way out. Where

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the material might have come from, and why it chose this moment to appear, no one could say.

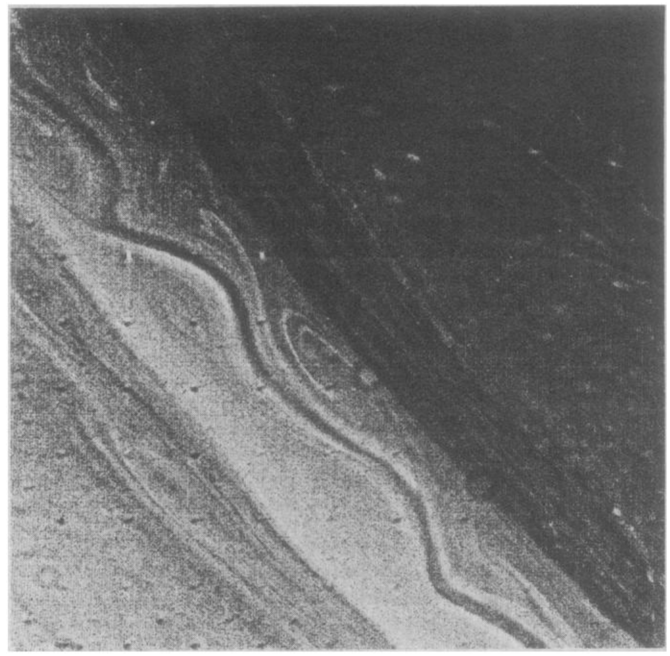
The impact of the platform malfunction on the Saturn encounter itself was amazingly slight. "My first reaction was 'Thank God it happened when it did and not a few hours earlier,' " said imaging team leader Bradford A. Smith of the University of Arizona. "We've accomplished most, if not all, of our major objectives," added chief Voyager scientist Edward C. Stone of the California Institute of Technology. With more than 17,000 pictures and other data to study, Voyager researchers will be productively engaged for quite a while.

Even leaving aside the scan platform anomaly, the Voyager 2 encounter with Saturn was no summer rerun of last November's encounter (*Science*, 5 Dec. 1980, p. 1107). Perhaps the most important single difference between the two spacecraft was the presence aboard Voyager 2 of a working photopolarimeter. (Voyager 1's instrument had failed during the Jupiter encounter in 1979.) In a key experiment during the flight over the ring plane on 25 August, the photopolarimeter recorded the light of the star Delta Scorpii as it flashed up through the mysterious ringlets, which subdivide the larger ring structure like grooves in a record. The readout (2700 meters of strip-chart) revealed an immensity of detail. At a resolution of 100 meters, Saturn's ringlets number not in the thousands, as seen in optical imagery, but in the hundreds of thousands.

Even as these data were coming in, moreover, the once favorite explanation of the ringlet structure was going by the boards. In an effort to obtain data to confirm their theory, Voyager scientists had devoted a long sequence of high resolution images to a search for extra-large ring particles—"embedded moonlets" 10 or 20 kilometers across—which presumably herd the smaller, meter-sized ring particles into ringlets by their gravitational interaction. But to a resolution of 1 kilometer, nothing was found. "We're now in the position we hoped we wouldn't be in," said Smith.

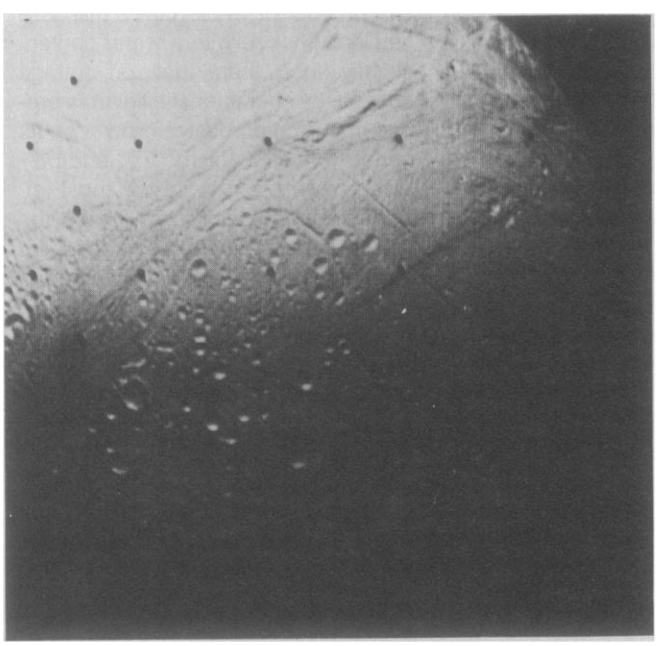
The winds of Saturn

Some Voyager scientists interpret this ribbon-like structure as a large-scale atmospheric wave analogous to the jet streams on Earth. Convection cells—analogous to Earth's high-pressure systems—nestle in the hollows.



Voyager 2 also outdid its predecessor in obtaining close-up images of many of Saturn's satellites, including Enceladus, Hyperion, and Iapetus. Except for the giant satellite Titan, the moons of Saturn were thought to be icy bodies ranging from a few hundred kilometers to about 1500 kilometers across—too small, according to pre-Voyager theories, to undergo much internal heating or to exhibit tectonic activity on the surface.

Not so. Voyager 1 had already seen signs of fissuring and resurfacing on Dione, Rhea, and Tethys; Voyager 2 revealed all that and more on Enceladus. Fissures, canyons, corrugated "ropey" terrain, a wide swath of surface wiped clear of craters—all bore witness to massive crustal deformation and internal heating. The current thinking is that Enceladus is heated by a tidal pumping mechanism similar to that which energizes the volcanoes on Jupiter's moon Io. Rhythmic tugging by Dione and Tethys force Enceladus to oscillate inward and outward slightly in its orbit; its deformation in Saturn's gravitational field then raises its internal temperature.



The icy enigma

Tiny Enceladus, a ball of ice 490 kilometers in diameter, shows evidence of internal melting and crustal deformation: lightly cratered grooved terrain, fissures, and "lava" flows—made by liquid water?—that have obliterated older craters.

Unusual features of another satellite, Iapetus, have long been known from Earth-based observations: the hemisphere that faces backward along Iapetus' orbit is literally as bright as snow, while the hemisphere that faces forward is darker than asphalt. Voyager 2 found a dark-side reflectivity of about 4 percent. This is darker than any silicate material such as basalt, but is consistent with carbonaceous chondritic material found on the very oldest meteorites and asteroids in the solar system. Voyager's measurements of Iapetus' density show that it is mostly ice, so it is difficult to see how the dark stuff could have welled up from the interior. But if the material is a layer of dust from outside, where did it come from? One guess is that it is from Phoebe, next outward from Saturn.

Voyager 2 revealed other new infor-

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Neptune's Rings Fading

Jupiter has one. Uranus has nine. Saturn has zillions. Could Neptune, the fourth and most distant of the giant gaseous planets, have none at all? Planetary rings, which astronomers had thought were unique to Saturn, are now seen as commonplace. Neptune would seem to be the natural place to find the next set of rings, but recent observations show that Neptunian rings, if they exist, are among the most tenuous of any in the solar system.

Attempted observations last May of Neptunian rings, the most sensitive searches conducted to date, were coordinated by James Elliot of the Massachusetts Institute of Technology. He and his group of cooperating observers watched through six telescopes as Neptune passed close to a star on the night of 10 May. To observers at Mauna Kea Observatory in Hawaii, the star appeared to pass just north of the planet. From the perspective of Mount Stromlo Observatory and Sieding Spring Observatory in Australia, it grazed the planet's pole. These astronomers were looking for even the smallest flicker of the star, which would mean that it had passed behind ring particles in orbit around Neptune. By chance Neptune passed in front of a second star only 2 weeks later on 24 May, but this occultation could only be viewed from the Southern Hemisphere. So, only Jay Elias at Cerro Tololo Observatory in Chile watched as the star cut across Neptune's equatorial region.

Elliot, who is one of the discoverers of Uranus's rings, was perhaps just a bit disappointed when nothing like an occultation by a Neptunian ring was observed. The two stars did on occasion flicker a bit more than might be expected from the effect of atmospheric turbulence, but none of these possible occultations was found to be real. Under some conditions, proving that such flickers are *not* occultations caused by rings or unsuspected satellites is difficult or impossible. Similar observations have led some to claim that asteroids have their own moons (*Science*, 20 March, p. 1333). But, because this observing group had three telescopes, which operated at two different wavelengths, at the same site in Hawaii, Elliot could rule out all of the suspicious flickers. In Chile, a single, distinct loss of starlight seemed to be an indication of a possible occultation for a while, but the duration proved too brief to have been caused by a ring. Diffraction of starlight would have made even an infinitely narrow ring appear to be 4.6 kilometers wide when the occultation is observed at the distance of Earth, but this one appeared to be only 2.7 kilometers wide.

Elliot cannot conclude that there are no rings around Neptune nor can he put very precise limits on the masses of any that do exist. He can, however, discuss just how hard they are to detect. He says that their telescopic system in Hawaii could have detected a 5 percent decrease in the light of a star. The ring around Uranus that is most difficult to detect causes four times that light loss, so a similar ring could have been readily detected around Neptune. But the dusty ring of Jupiter has so far proved too tenuous to be detected by observation of an occultation.

How massive an undetectable ring could be depends on the size of its particles, Elliot says. If a ring of fine dust had a mass equal to that of a 1-kilometer-wide satellite and the ring was 5 kilometers in diameter, it could have been detected. On the other hand, a ring could be made up of innumerable 1-kilometer bodies and still not have been detectable from Earth. Thus, something like the ring of Jupiter remains a possibility for Neptune, but rings as substantial as the main rings of Saturn or the rings of Uranus can be eliminated.

Opportunities to place even tighter limits on Neptunian rings will be scarce in the next few years. The next good occultation will occur in 1983, but it will tighten the limits of detectability by only a factor of 2. The flight of the Space Telescope and a Voyager flyby are scheduled for the last half of the decade. But given enough patience, Elliot says, searchers for Neptunian rings will be rewarded. As Neptune's large satellite Triton spirals closer and closer to the planet, it will eventually come too close and be torn to pieces by Neptune's gravity, forming an impressive ring. Astronomers will only have to wait 100 million years.—RICHARD A. KERR

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mation as well. Before the present flyby, says imaging leader Smith, the little satellite Hyperion was high on his private list of uninteresting objects. But images were taken anyhow, revealing a bizarre, irregular body that resembles nothing so much as a hamburger patty. Moreover, Hyperion turns out to be tilted at 45° to the plane of its orbit, a position that should be unstable. Is it tumbling? It is hard to tell from the images in hand. But Smith concedes that he now puts Hyperion on a very different list.

There are a number of reasons why the Voyager 2 images of Saturn look better than those of its predecessor. For one thing, the rings were brighter the second time around. Voyager 1 arrived not long after the Saturnian equinox, when the rings are edge-on to the sun; the spacecraft saw them illuminated at an angle of only 1°. For Voyager 2 that angle had advanced to 7°. At the same time, the Voyager 2 cameras have turned out to be slightly more efficient than Voyager 1's, giving the images a higher contrast and a generally crisper look. (It was the luck of the draw, says Smith: no two vidicon tubes are exactly alike.)

The improvement in the images has paid off especially for the atmospheric scientists on the Voyager team. Convective features and jet streams, much better defined this time around, will be easier to study. In addition, notes Verner E. Suomi of the University of Wisconsin, the new details will help in the mapping of the Saturnian winds. Struggling to track the motion of dimly defined cloud features in Voyager 1 images, Suomi and his colleagues found equatorial jet streams raging at 1800 kilometers per hour—four times faster than the jets on Jupiter. Moreover, they found that all the winds on Saturn seem to blow eastward, in marked contrast to the east-west alternation of winds with latitude seen on Jupiter.

Preliminary maps of the winds made from Voyager 2 images showed that this is not quite the case. The east-west pattern is there on Saturn, but only at higher latitudes than on Jupiter. Wind velocities on both planets fall off rapidly away from the equator. But Saturn shows a very weak westerly jet as far north as 75°. On Jupiter, the jets have terminated by 50°N. Another puzzle, notes Gary E. Hunt of the University College, London, is that on Saturn, the jet streams show no correlation to the banding pattern of the clouds, whereas on Jupiter that correlation is very strong.

—M. MITCHELL WALDROP

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