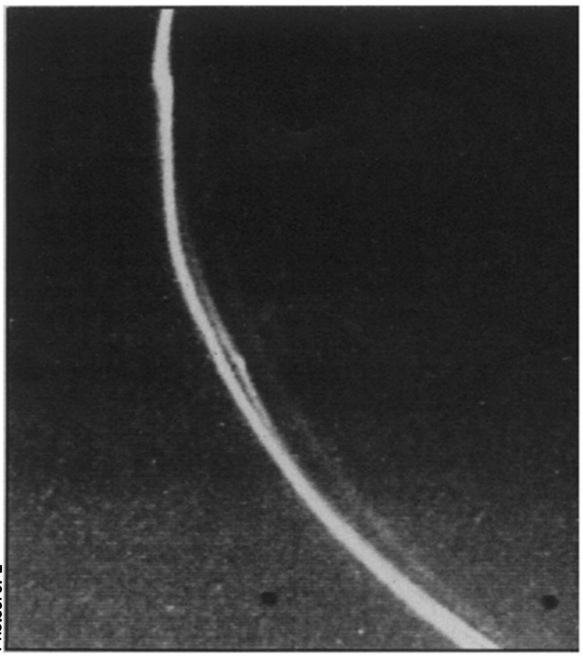
Voyager 1's Saturn: Moonwatch

Saturn's giant moon Titan has long held a special allure as the only satellite known to have a substantial atmosphere — an atmosphere theorized by some researchers to be depositing thick layers of organic goo on the surface and perhaps to resemble that of the primitive, prebiotic earth. Last week the Voyager 1 spacecraft flew within about 4,000 kilometers of the place, revealing it to be fully deserving of its exotic reputation.

The probe never actually saw the surface, wrapped in dense clouds and topped with layers of photochemical smog, but it was able to show the nature of the wrapping. Estimates of Titan's surface atmospheric pressure have ranged from 20 millibars (earth's is about 1,000) to 20,000, largely because one suspected major component — nitrogen — was undetectable from earth. Pre-Voyager data could only suggest the presence of perhaps 20 mb of methane, hypothesized source of the organic goo. Voyager 1's trajectory was carefully designed so that the craft's earthward radio signals would pass through the Titanian atmosphere, modifying the signals in a way that would yield a "profile" of pressure and temperature extending all the way to the ground—or until the atmosphere simply gobbled up the whole signal at about 3,000 mb of pressure, whichever came first. Only the upper part of the profile could be analyzed in the days immediately following the flyby, but it was already showing a pressure of 1,500 mb with no bottom in sight. Infrared and other measurements indicated the overwhelmingly dominant constituent indeed to be nitrogen, and a simplified assumption of a 100 percent nitrogen atmosphere would lead to a temperature at the 1,500 mb level of 92 K (−181°C). A similar radiometric temperature calculated from earth-based data prompted Von R. Eshelman of Stanford University to speculate that the surface pressure might be about 2,750 mb. Infrared data revealed a number of hydrocarbon molecules presumably from the methane (including HCN), although, Eshelman said, methane seems to be such a minor component of the total atmosphere that a heavy concentration of hydrocarbon surface goo is unlikely.

Although it was unclear whether the completed profile would show the surface temperature to be much higher or lower than that at the 1,500 mb level, the cold upper atmosphere suggested the possibility of such exotica as liquid nitrogen lakes and clouds and even rain (although depending on the lower-atmosphere temperature structure, the droplets might never reach the ground). Still, said Tobias Owen of the State University of New York, a slight warming trend visible at the bottom of the existing profile might be a sign that the nitrogen produces a slight greenhouse effect. In addition, Titan generates a weak hydrogen torus around its orbit, and though its magnetic field if any is less than a thousandth of earth's, it does have a leading magnetic "tail' produced by the faster rotation of Saturn's field.

But Titan is only one of a family now known to include at least 15 satellites, many of which got their first close scrutiny from Voyager 1's cameras, revealing a wide range of individual curiosa. Innermost (unless more are discovered, which could happen even with the existing photos, once busy scientists find time to study them in detail) is the 15th, the most recent addition to the list, which seems to be responsible for gravitationally holding the wide A-ring in place. Next out are 14 and 13, credited with similarly confining the bizarrely twisted F-ring. About 10,000 km farther from the planet are numbers 11 and 10, their orbits differing in radius by a mere 48 km — a seeming collision course except that the two moons are expected to swap orbits in a gravitational gavotte next anticipated for January of 1982.

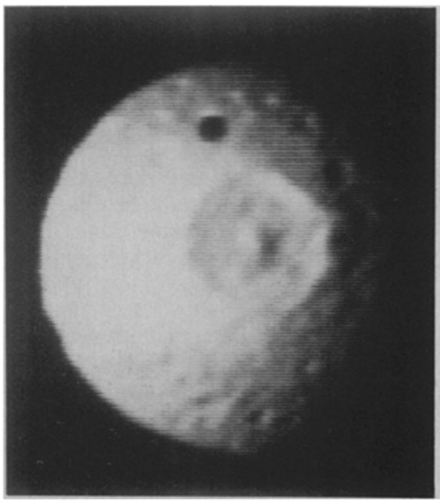


Photos: JPL

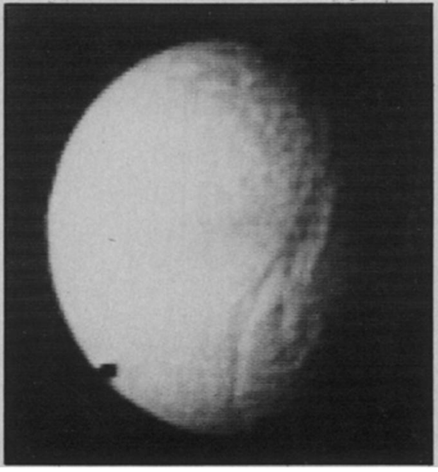
Close-up of F-ring reveals its strangely "braided" multi-strand structure, one of Voyager 1's most puzzling finds, possibly associated with electrostatic effects.

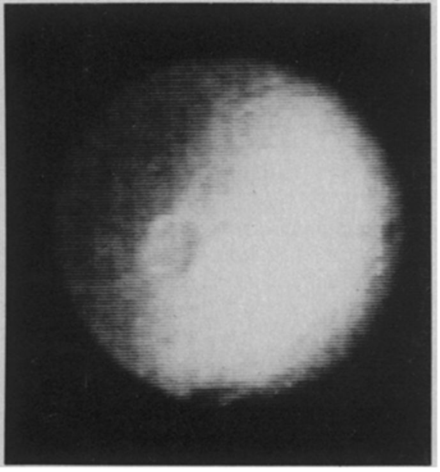
As if this were not a surprising enough find, one of the dancing duo was even responsible for the discovery of yet another ring around the planet. A thin, dark stripe noted on number 11 in one photo was found to be in a different position in a photo taken 13 minutes later. The conclusion: The stripe appears to be the shadow cast by a previously unknown ring — now dubbed the G-ring — lying between the F-ring and the satellite, and facing the little moon edge-on.

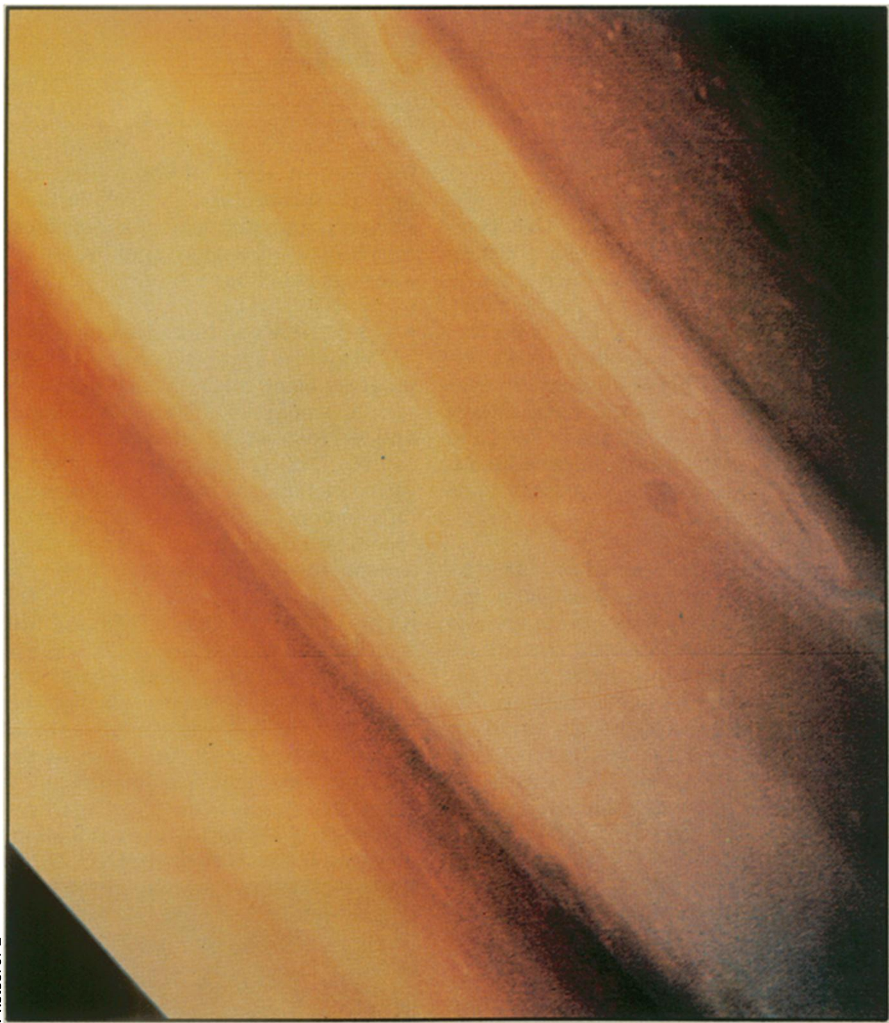
Out beyond all that complexity lie Saturn's nine "established" satellites (plus a tenth — a tiny object discovered from recent ground-based observations to be sharing the orbit of Dione). Voyager 1's images have provided not only the first



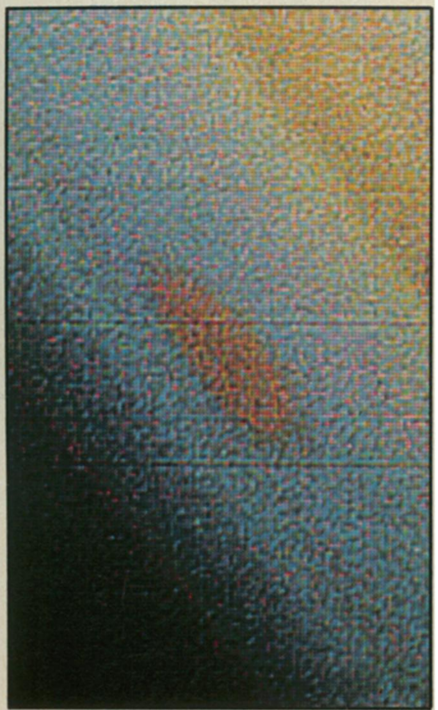
Large valley on Tethys (left) may be a crack caused by impact on opposite side (right).

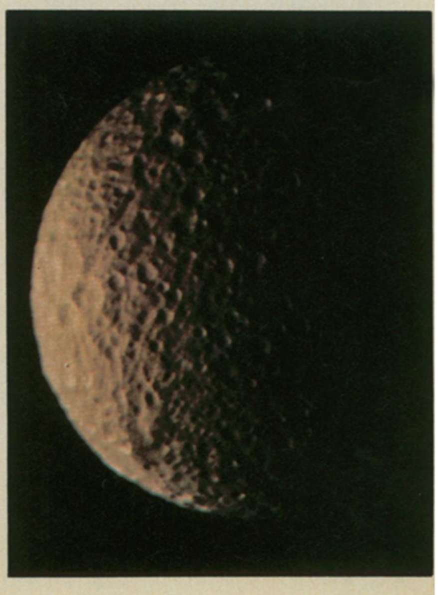


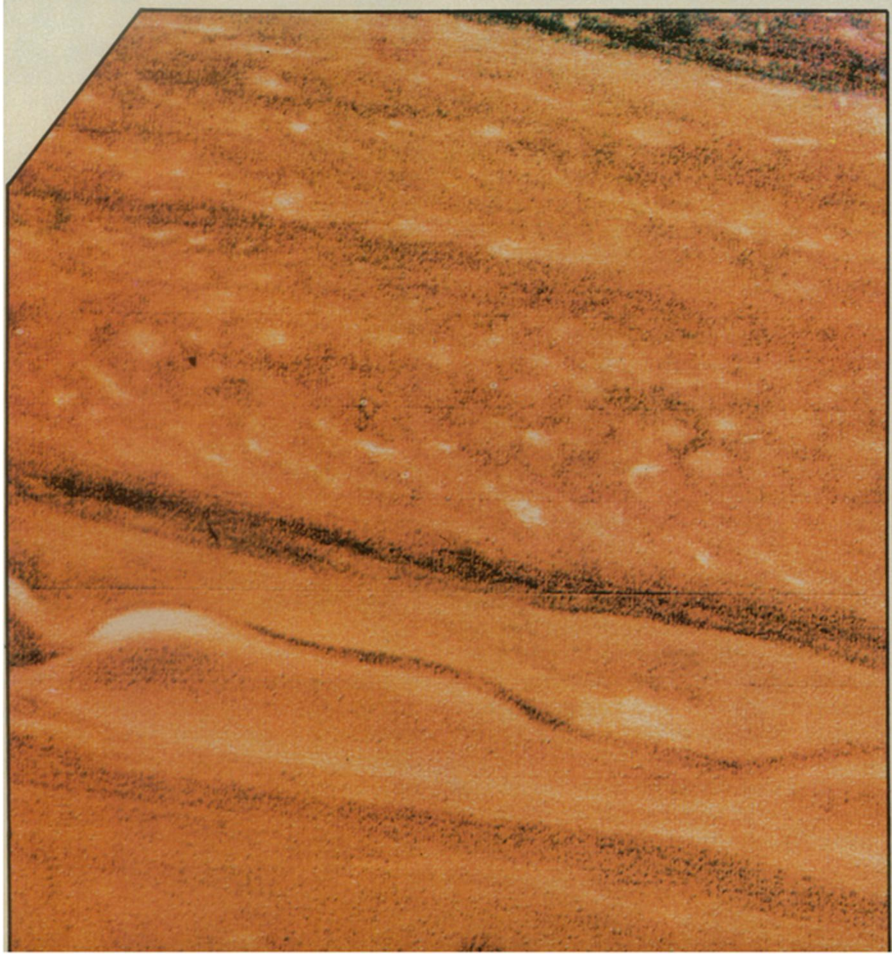




From 7.5 million kilometers out, Saturn's visible clouds (left) show subtly colored bands, but except for two brownish 10,000-km-long ovals there are few of the sorts of turbulence features prominent on Jupiter. From a closer-in 2 million km, however, high northern latitudes (lower left) reveal numerous small-scale features such as these white markings, whose chevron-like array is indicative of local circulation patterns. False-color image (below) shows southern-hemisphere oval feature resembling a one-third-size version of Jupiter's Great Red Spot. The heavily cratered surface of the satellite Mimas (bottom) hints at a large, trench-like feature trending north-south, while its opposite face (bottom left of facing page) is dominated by a huge crater whose 9-km-high walls may be the tallest yet found in the solar system.



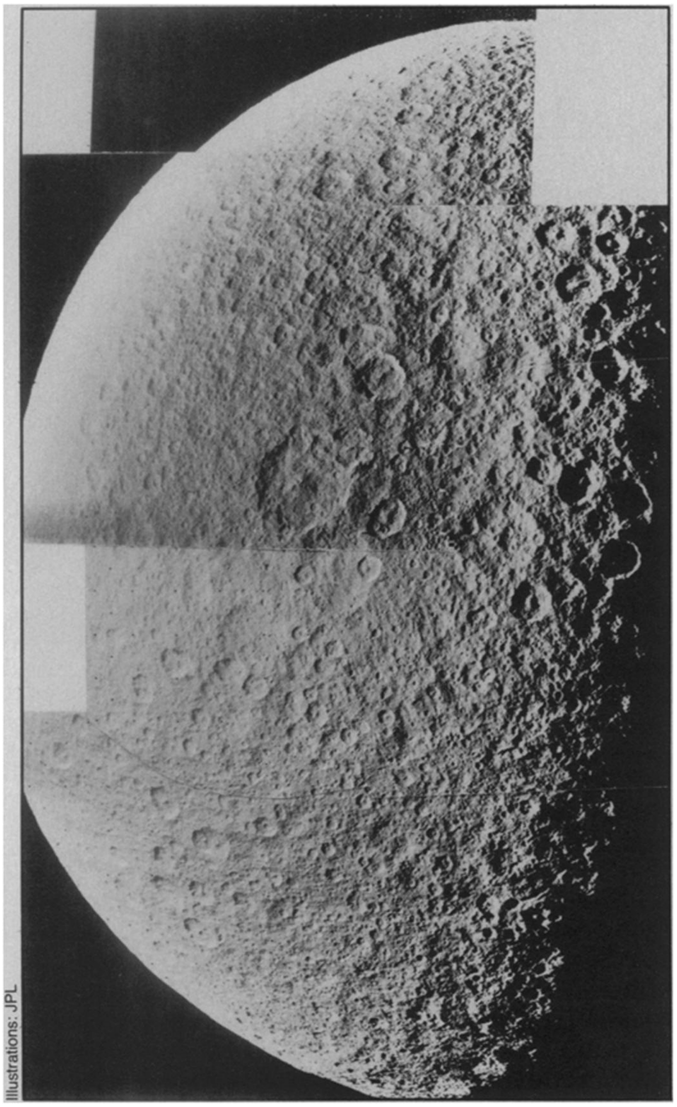




Photos: JPL

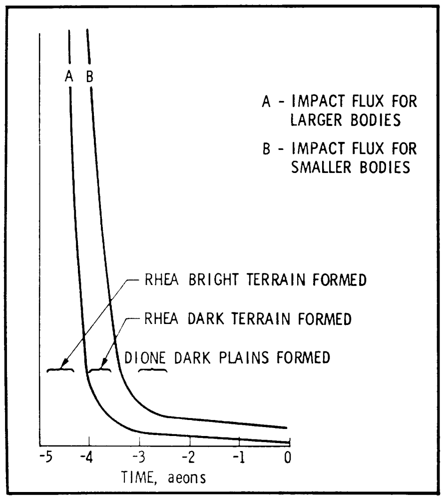
close looks at many of them, but greatly improved measurements of their sizes, critical in calculating their densities and estimating their compositions. And therein may lie the beginnings of a mystery. Before Voyager 1's flyby, says Laurence Soderblom of the U.S. Geological Survey, there were two contrasting expectations of how the moons' densities might vary: Either they would get less dense with increasing distance from Saturn, based on the idea that increasing proportions of lightweight volatile materials would have been available farther from the hot center of the proto-Saturn nebula when the moons were formed, or they would all be the same, in the event that the proto-Saturn's heat was too little to differentiate the material mixture. Yet an early look, says Soderblom, suggests that neither may be true. Only three precise densities were initially available from Voyager data (though more will follow when gravitational perturbations in the spacecraft's trajectory can be factored in), but their implication, in Soderblom's view, is "weird." Close to Saturn is Mimas, at 1.2 ± 0.1 grams per cubic centimeter. Two moons out is Tethys, which is indeed less dense at 1.0 ± 0.1, but next in line is Dione, at 1.4 ± 0.1. Calculations for the other satellites are necessary to fill in the picture (some must wait for Voyager 2), but it seems at least possible that there will turn out to be no regular progression at all. Recent studies of isotopic anomalies in meteorites have hinted that the early nebula from which the solar system formed was not completely homogeneous or smoothly gradated; perhaps the message of Saturn's moons is that similar irregularities existed on a planetary scale. Or, suggests Soderblom, given the small density decrease from Mimas out to Tethys and the larger step up to Dione, perhaps the progression is "backwards." In Soderblom's words, "Hmmm."

The surfaces of the satellites are, not surprisingly, surprising. Mimas is heavily cratered everywhere, but most prominent is a single huge crater, about 130 km across, branding a moon shown by Voyager's data to be only 390 ± 10 km in diameter. The crater walls loom an estimated 9 km high, surrounding a 4-to-5-km central peak. The structure is on the side of Mimas that faces Saturn, an improbable direction from which to expect a single major meteorite impact, but Eugene Shoemaker of the USGS suggests that the blow might have reoriented the whole satellite. One photo of the feature, framed right in the center of Mimas like a rocket nozzle on some spherical spacecraft, was promptly dubbed the "Death Star picture," after *Star Wars* villain Darth Vader's huge space station. According to Soderblom, many of Mimas's craters also appear to be deeper for their diameters — more bowl-like — than is typical of earth's moon or Mercury. This could be because Saturn's ice-rich satellites are cold enough to prevent

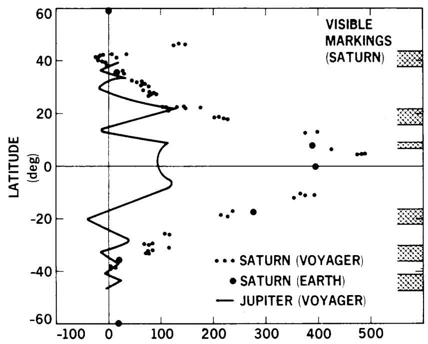


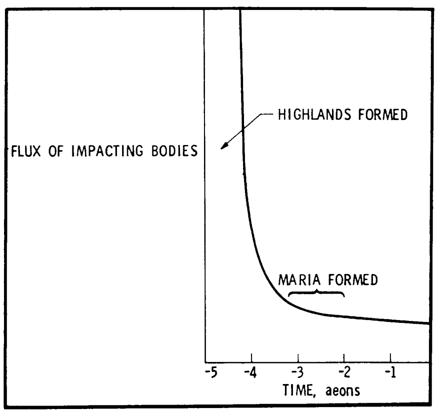
Photomosaic of Rhea shows heavy cratering throughout, but with large craters nearly absent from lower right quadrant. Did Rhea's early cratering happen in two separate episodes of bombardment? The answer could significantly alter ideas about the evolution of other planetary surfaces such as Jupiter's Galilean satellites.

Comparison of circumferential winds on Jupiter and Saturn reveals Saturn's equatorial wind belt to be four times as fast and twice as wide as Jupiter's (below).



The patchy distribution of large impact craters on Rhea could indicate multiple cratering episodes (above) at odds with the single cratering-flux curve derived for earth's moon (right) and often applied to studies of other planets and satellites.





solid-ice flow from filling them in, and too low in mass for gravity to cause them to slump. Study may show this as a characteristic difference between the Saturnian moons and larger bodies, but a similarity with smaller objects such as the Martian satellite Phobos, which is dominated by a deep crater called Stickney.

Out from Mimas is Enceladus, of special interest because a 2:1 orbital resonance with Dione may cause it to be subjected to the same tidal stresses linked with the volcanism on Jupiter's moon Io and the cracked but otherwise smooth surface of Europa. Though Voyager 1 got no closer than 200,000 km (Voyager 2 will do far better), the limited-resolution photos suggest to Soderblom that Enceladus (diameter 500±20 km) may be Saturn's least-cratered moon — right next to heavily bombed Mimas.

Next is Tethys (1,050±20 km), also to be better seen by Voyager 2, revealing a 750-kilometer-long trench on one side and a 180-km circular feature — probably an impact crater — on the other. Some researchers suggest that the trench may be a crack formed by the blow. Shoemaker goes considerably further, maintaining that many craters on Saturn's moons look more irregular than do those on rocky worlds, as if they resulted from impacts into surfaces that were already heavily shattered. On such low-gravity objects, he notes, such crustal irregularities could well be the dominant factor in the appearance of subsequently formed craters.

Of the entire Saturnian family, Dione (1,120±20 km) looks the most like earth's moon. Smooth areas separate many of its numerous craters, similar to the intercrater plains caused by lava flows on other bodies — but Dione is mostly ice. Dione's density, Soderblom observes, could mean that it contains enough heat-producing radioactive elements for the crust to have remained capable of resurfacing itself until after its early meteorite-bombardment episodes were over. Sinuous "valleys" may indicate cracks in the crust, while light-colored "wispy" features on the surface have been tentatively interpreted as "leaks" of volatile material from within.

Rhea (1,530±20 km) bears more scars than it has room for, with craters upon craters, large and small. Strangely, Soderblom notes, part of the surface seems to lack the large craters that are part of the mix everywhere else — a seemingly innocuous difference, but with what Soderblom sees as potentially far-reaching consequences. The general opinion has been that the cratered bodies in the solar system received most of their meteorite impacts during a single span of years called the "great bombardment" early in the system's history. So why, the scientists ask, should one part of Rhea, just as pitted as the rest in terms of numbers, show a different range of crater sizes than the one usually thought to characterize the great bombardment? One possibility, he suggests, is that more than one bombing took place, with the latter "bombs" representing a population of objects with a different size range — comet nuclei, perhaps, or debris orbiting the early proto-Saturn.

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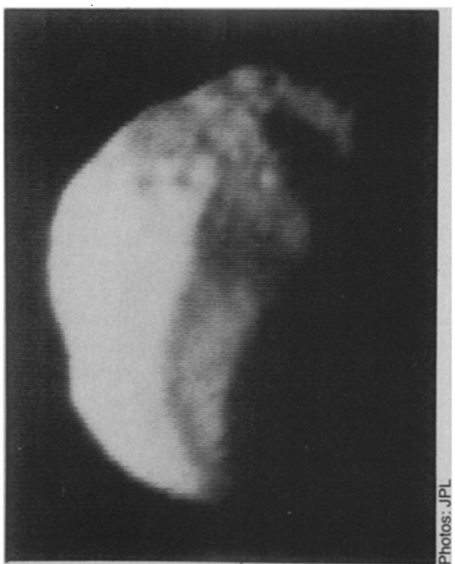
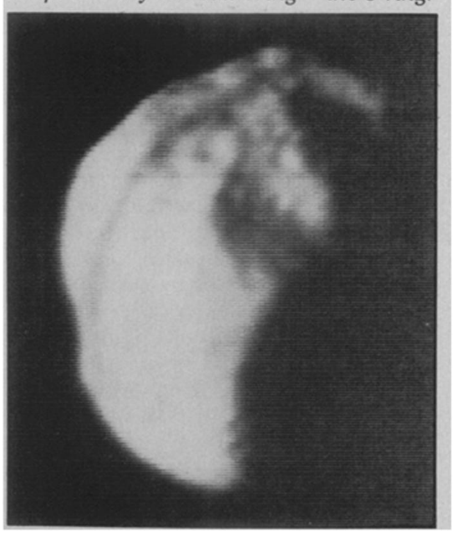


Thin stripe on Saturn's 11th moon was seen to have moved in images taken 13 minutes apart, revealing it to be the edge-shadow of a previously unknown ring — the G-ring.



Interferon: The explosion continues

The promise of interferon has yet to be fulfilled, but much promising research on the putative anticancer and antiviral agent has been reported since Charles Weissmann of the University of Zurich and of Biogen announced production of interferon with recombinant DNA techniques (SN: 1/26/80, p. 52). An update on interferon was presented last week in Washington at the first annual Congress on Interferon Research, and the news was encouraging.

David Goeddel of Genentech in San Francisco, for instance, reported that interferon has now been produced via recombinant DNA techniques not only by Biogen but by three other genetic engineering companies as well — Genentech, Genex of Rockville, Md. and Cetus of Berkeley, Calif. Whereas only several molecules of interferon per *E. coli* cell could be made in January, 20,000 to 30,000 molecules can now be produced. What's more, not only interferon from leukocytes (white blood cells) but interferon from fibroblasts (connective tissue cells) can now be made with recombinant DNA. In fact, as Weissmann predicts, interferon supplies made with recombinant DNA may become available for clinical trials as soon as a year and a half from now.

Other new ways of making larger and more economical batches of interferon also look promising. For instance, Flow Laboratories in McLean, Va., is now growing fibroblast cells on beads of sugar called dextran instead of in petri dishes in order to make fibroblast interferon for National Cancer Institute clinical trials. Pharmacia Fine Chemicals in Uppsala, Sweden, is also producing fibroblast interferon this way. The reason is that the dextran beads increase the surface for fibroblast cell growth over that of petri dishes and hence increase the cells' production of interferon. The technique offers a way to make substantial amounts of fibroblast interferon for clinical trials *now*, M.C. Hirtenstein of Pharmacia explains, although the recombinant DNA production of interferon will probably eventually outstrip the dextran bead method.

Meanwhile, investigators are using the limited interferon now available to conduct clinical trials of interferon's potential as an anticancer drug. Preliminary results from these studies suggest that interferon can counter some human cancers, but will not be a cancer panacea. For instance, J.U. Gutterman of the M.D. Anderson Hospital in Houston and colleagues have given interferon to 29 patients with advanced colon, prostate and ovarian cancers, which are extremely resistant to drugs. Three of the patients experienced partial remissions, eight some improvement and 18 had no response. J. Treuner of Tübingen University in Tübingen, West Germany, and his co-workers have given interferon to six neuroblastoma patients. One had a total remission, two partial remissions. Ernest C. Borden of the University of Wisconsin at Madison reports that he and his team have found interferon can make recurrent breast cancer regress, but only in some patients. "There is nothing in the data now that suggests that interferon is a cancer cure," Borden concludes. However, there has been a lot of progress in treating various cancers during the past 15 years, he says, and he foresees "interferon adding something to the other treatment advances."

Although interferon has long given evicarried across the Atlantic.

Even less well understood is the effect of rings like 79-H on the energy and heat balance in the ocean, says Richardson. But these and other questions will soon be addressed. A three-year project on warm rings is slated to begin next year, involving 13 institutions and directed by Terry Joyce of WHOI. According to Wiebe, who will be among the investigators, the project will use ships and buoys to examine the warm rings' chemical, biological and physical structures both horizontally and vertically.

But back to 79-H. Throughout the summer, ring 79-H continued to wend its way along the coast under the watchful eyes of satellites and researchers. At the beginning of September, says Fitzgerald, the ring bumped into a Gulf Stream meander and began to fade from satellite images as the temperature difference between its waters and those of the slope lessened. Even so, the researchers were still able to pick out the position of the shrinking ring because of the colder shelf water it pulled around itself. Finally, late in October, 79-H met the inevitable fate of all warm rings. Having survived far beyond the usual six-month lifetime of a warm ring, 79-H shrank to almost nothing and merged with the Gulf Stream near Cape Hatteras. Unusual in many respects, 79-H was certainly not the last warm ring to spin past the AEG researchers. And the more that come along, the more they will learn. □

. . . Saturn

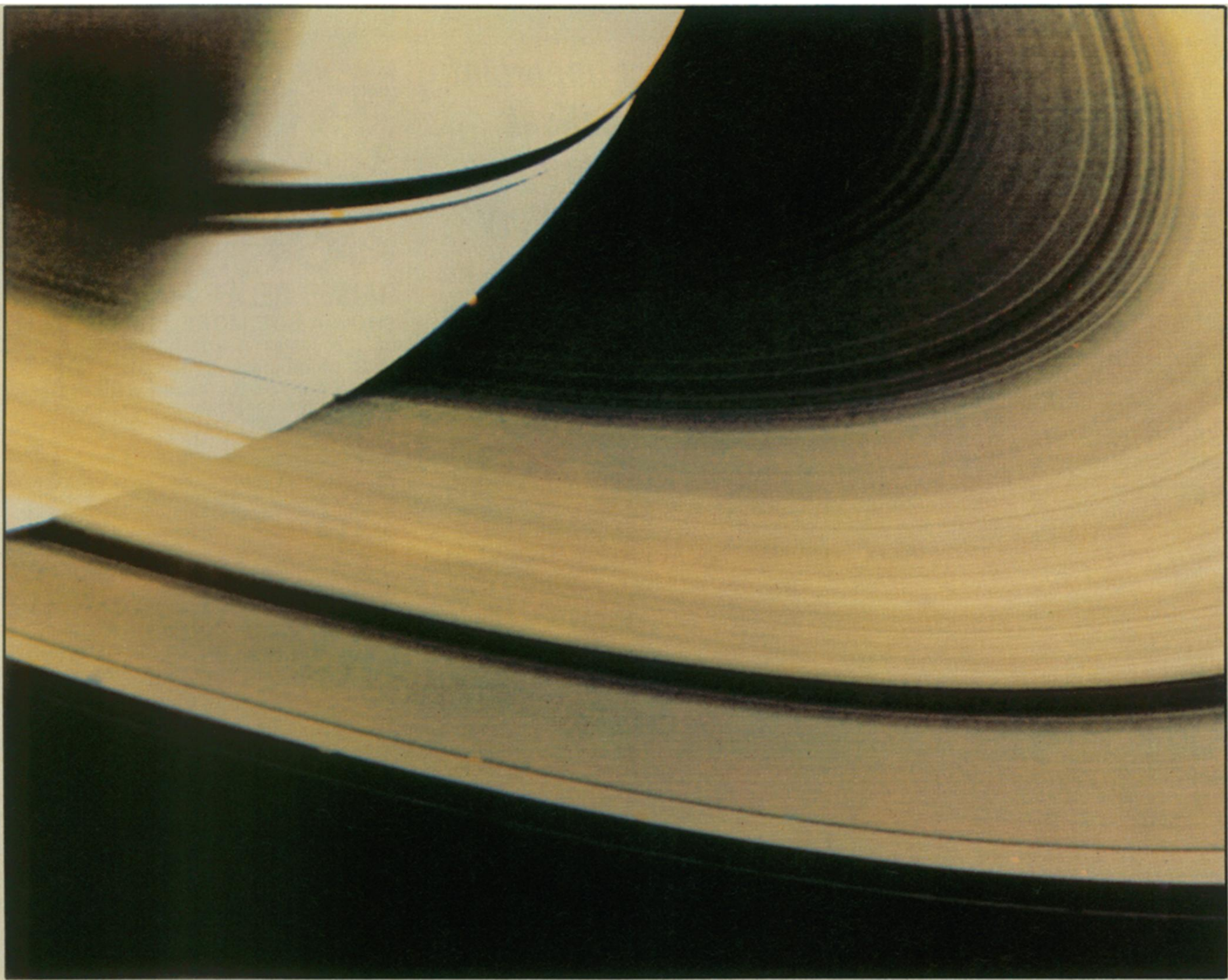
Such events might well have taken place on other objects, he notes, but the evidence could be preserved on Rhea because part of the original crater population was smoothed over by ice flows from within the satellite, leaving a "clean slate" on which the later impacts could be discerned. Such multiple bombardments should be considered, Soderblom says, before calculations based on the craters of earth's moon (which lacks such a clearly defined small-craters-only patch) are applied to vastly different objects such as Jupiter's Galilean satellites.

The outermost Saturnian moon viewed by Voyager 1 was Iapetus (1,440±40 km), an oddly two-faced object with one hemisphere several times brighter than the other. Prior to the flyby, the most-heard explanation for the difference was that dark material from the moon Phoebe (still farther out) was being somehow transported to Iapetus, where it caught up with the satellite from behind and darkened the otherwise ice-covered object's trailing side as it moved in its orbit. Voyager 2 will take a closer look, but the fine details of the light-dark boundary seen in even Voyager 1's photos prompt Soderblom to believe that the dark material must have reached the surface as a result of the internal thrashings of Iapetus itself.

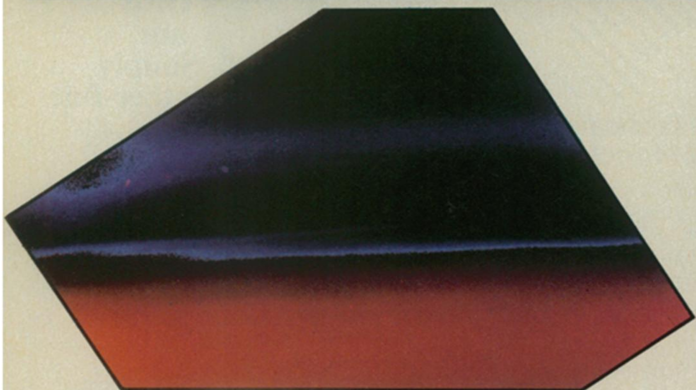
Besides probing the satellites, Voyager 1 continued to show new details of Saturn's spectacular rings. Even in a relatively low-resolution photo, Richard Terrile of Jet Propulsion Laboratory counted 360 individual "ringlets," and extrapolated from high-resolution coverage of small areas that the actual total is probably more than 1,000. Furthermore, he says, it is quite possible that by the time Voyager 2 takes its look in nine months, the details may have changed. If the ringlets are due to satellite resonances, the objects causing the resonances may have moved relative to one another; spiral gravitational density waves, another cited possibility (also linked by some researchers with the spiral structure of galactic arms), would tend to propagate outward, shuffling the ringlet particles some more.

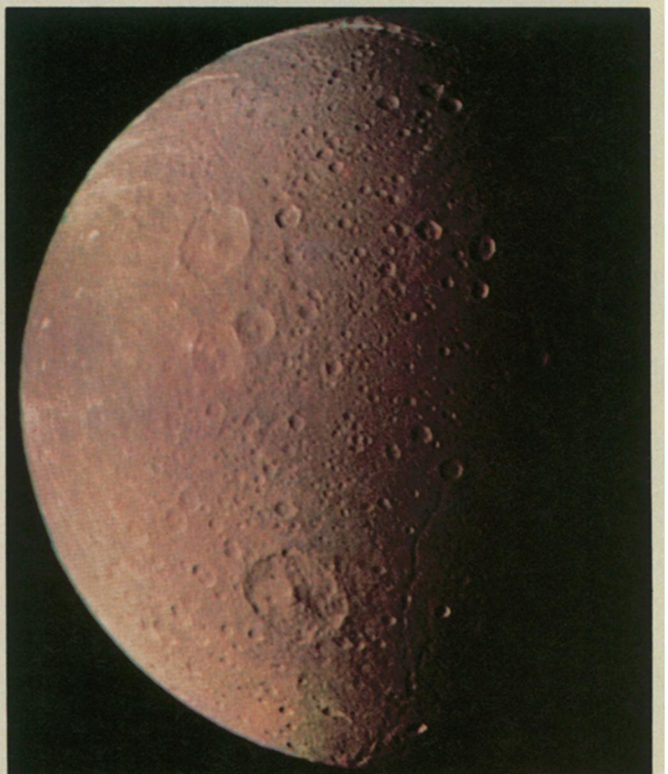
Terrile also offered a tentative hypothesis regarding the strange, radial "spokes" in the wide B-ring, which have baffled researchers by seeming to ignore the fact that ring particles close to Saturn should circle the planet faster than those farther out, thus tearing such spokes apart. The spokes appear dark by back-scattered light and bright by forward-scattered light, suggesting them to consist of small particles, Terrile noted. Perhaps electrostatic charging, enhanced when the particles pass through Saturn's shadow, lifts them slightly out of the main ring plane so that their scattering characteristics show, and the thus-charged particles are then carried around by Saturn's magnetic field — which just happens to rotate at about the same speed as particles in the middle of the B-ring, the only ring in which the spokes have been seen. Electrostatic forces may also have something to do with a yet more baffling phenomenon — the "braided" and knotted structure of the multiple ringlets revealed in close-ups of the thin F-ring. But the mystery remains. Even Saturn's powerful radio emissions may originate at least in part from the rings' vicinity, says James Warwick of Radiophysics, Inc., in Colorado, who reports the apparently ring-based bursts to represent about 3 million watts of power. (Saturn's seemingly obvious ionosphere is not their source, he says, because the bursts contain low frequencies that the ionosphere would have cut off.) The rings also almost certainly include the necessary conditions (electric fields, particle collisions, etc.) for another phenomenon, lightning, Warwick adds, but their lack of a dense atmosphere probably precludes bright optical flashes — and indeed, none were initially reported in Voyager's photos, which had revealed lightning "superbolts" around Jupiter.

In the time pressure of Voyager 1's myriad close encounters, many of the project's scientists have yet even to see all of their data, and Voyager 2 will add to the file during its own flyby next August. Voyager 1, meanwhile, is now heading out of the solar system at a steep 35.5° inclination to the plane of the ecliptic, on its way to the stars. Next week: The visible and invisible Saturns. □



Photos: JPL





Spectacular swath of Saturn's rings (top) was photographed from 1.5 million km as Voyager 1 was climbing steeply away from the planet. Varied densities within the wide B-ring are revealed by the broken visibility of the planet's limb through the ring. Also shown are the thin, outer F-ring and material within the Cassini division. (Faint haze along planet's upper limb is residual image from previous photo. Bright spot on limb is artifact of camera system). Multi-layered hazes topping the dense atmosphere of Titan (above) are emphasized in this computer-colored image indicating divisions in the haze at altitudes of 200, 375 and 500 km above the virtually opaque top of the atmosphere. The satellite Dione (right) seems to show relatively smooth material separating its craters, suggesting that it was resurfaced by solid-ice flows or other activity since its original bombardment. Sinuous valleys probably traced faults in the icy crust.