Rings Around the Solar System

Thought for centuries to be unique, Saturn's rings have recently been joined by those of Uranus and Jupiter—it was an uphill battle

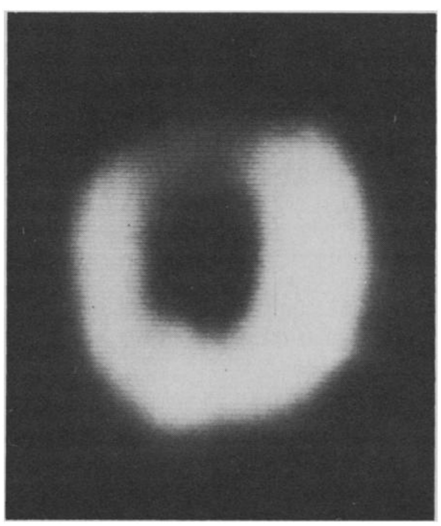
When Pioneer 11 was launched 6 years ago, it was heading, by way of Jupiter, toward the "unique ringed planet of Saturn." By the time it arrived last month, Jupiter and Uranus had joined the club of ring-encircled planets. The study of planetary rings has been in an uproar ever since these unsettling discoveries. Jupiter, according to widely held theories, should not have any rings at all. Uranus's nine rings are impossibly narrow if Saturn's are taken as any standard. And now Pioneer has discovered two new rings of Saturn—one is more like a Uranian ring, and the other may be more like an "asteroid belt" than a ring.

All of these discoveries have burst upon a generally unsuspecting, even unconcerned, scientific community. Interest in possible ring systems around planets other than Saturn had been almost nil. Carl Sagan of Cornell University summed up the prevailing attitude when he asked in a 1975 survey of the solar system: "Only Saturn has rings. Why?" Today, theoreticians are asking instead how the same basic principles of physics can account for the three kinds of ring systems now known. Everyone is wondering how many more rings remain to be discovered.

The first surprise for ring specialists, the discovery of the rings of Uranus in 1977, was completely serendipitous. James Elliot, now at the Massachusetts Institute of Technology, and his group were flying over the Indian Ocean in NASA's Kuiper Airborne Observatory waiting to make telescopic observations of the passage of a faint star behind Uranus in order to obtain data about the planet and its atmosphere. But they had a problem. A week before the expected occultation, an error in the location of the star had been found. Elliot feared that the star might miss Uranus entirely and provide none of the hoped-for information. Rings were an afterthought. "We had been joking that, if it was a near miss, we could always salvage something from the whole effort by placing an upper limit on the mass of any hypothetical ring material," he recalls.

So when the star's light first nearly flickered out 35 minutes before the calculated occultation time, explanations other than rings came to mind. The star flickered five times before the occultation by Uranus and five times after. Even after the possibility of clouds and mechanical problems had been eliminated, the group preferred nonring explanations, although none was entirely satisfactory. The objects responsible for the flickerings, which were initially termed swarms of "small bodies in orbit around Uranus," were simply too narrow to be rings. Two days later, when the precise symmetry of the ten flickerings about the planet became obvious, the group finally accepted the reality of the first non-Saturnian ring system.

The discovery of a new, five-member ring system did not at first deter theorists. It seemed clear that, as in the Saturnian system, some of the known major satellites of Uranus kept the small particles of the rings in position. Then in 1978 Elliot's group found four additional rings around Uranus. It became obvious that interactions with the known satellites could not explain the presence of that many rings.



A "picture" of the Uranian rings in the infrared spectrum taken by Keith Matthews, Gary Neugebauer, and Philip Nicholson of the California Institute of Technology. They scanned the planet and rings at two different wavelengths in the infrared. At one wavelength the planet was more reflective than the rings, and at the other it was less reflective. By subtracting one image from the other, only the rings are left. They are actually much narrower than they appear here because the image was distorted by Earth's atmosphere. By analysis of the rings' reflected light, it appears that they are made up of rocks that are twice as dark as those on Earth's moon, rather than the icy balls thought to make up Saturn's rings. [Source: Caltech]

The biggest problems for theorists so far are that the Uranian rings are as little as 5 kilometers wide and the widest ring has surprisingly sharp edges. Apparently some special gravitational effect very efficiently keeps particles in the rings and out of the gaps between them. Without some force to confine them, ring particles would eventually spread out into a disk because each particle collides with another every few hours. Any confining mechanism must be underlain by the basic principles of Newtonian physics, but the theorists' difficulties are greatly compounded because rings are made up of billions of particles. Peter Goldreich of Caltech explains that "although the behavior of a single particle is straightforward, when whole clouds of them get together they do all sorts of things that they wouldn't have thought of by themselves."

One thing they do that is well understood is migrate into the equatorial plane about a planet. If they are evenly distributed in orbits about the planet, collisions between the particles will cause them to drift into the plane of the equator where the equatorial bulge of the planet has created a "gravity well." Here, the particles can be closer to more of the mass of the planet than in any other orbit. Left to itself, this disk, which in the case of the major rings of Saturn spans hundreds of thousands of kilometers, would be only one particle (that is, tens of meters or less) thick. Even if any likely disrupting influences are taken into account, it would probably be no more than 1 kilometer thick.

Why a thin disk such as this should be divided into many different rings is not so well understood, even in the familiar case of the Saturnian rings discovered by Galileo 300 years ago. The gap, called the Cassini division, between the outer

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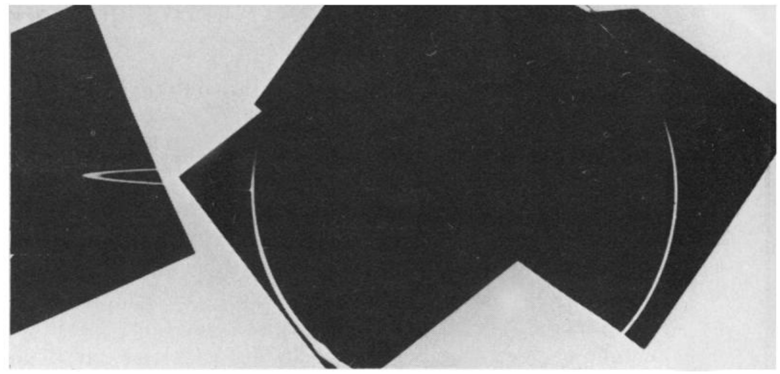
or A ring of Saturn and the middle or B ring, is apparently caused by Mimas, an inner moon of Saturn. Mimas has been implicated because it orbits Saturn in exactly twice the time that any particles happening to orbit within the Cassini division would. This whole-number relationship of orbital periods is called resonance.

Although no consensus existed about exactly how Mimas's gravitational attraction manages to clear away particles having orbits in resonance with itself, substantial progress was being made toward explaining the known ring structure of Saturn. And then there were nine new, narrow Uranian rings to be explained.

Several theories have been advanced to help explain the perplexing Uranian rings. Goldreich and Scott Tremaine of the Institute for Advanced Study in Princeton have proposed that such rings might result from the gravitational herding of ring particles by small undetectable moons on either side of each ring. Also, the gravitational attraction of the ring particles for each other may maintain the elliptical shape of the widest ring, which would otherwise quickly become circular. Ten tiny satellites, each perhaps 1 kilometer across, would orbit about 500 kilometers outside each ring, according to this theory. Goldreich and Tremaine concede that, even if their theory is correct as far as it goes, many questions remain unanswered. For example, it does not mention the origin of the rings and it strictly applies only to circular rings.

According to a rival theory, a small satellite lies within each of the nine rings rather than alongside them. Stanley Dermott and Thomas Gold of Cornell University and Andrew Sinclair of the Royal Greenwich Observatory suggest that one or more larger satellites of Uranus drifted too close to the planet and were broken up by gravitational forces into nine smaller satellites. Each of these satellites has since shed small particles that have become gravitationally trapped in a nearly complete, horseshoe-shaped ring with the parent satellite in the break of the ring. The same type of confining mechanism has trapped the Trojan asteroids so that they orbit the sun as two groups in a triangular formation with Jupiter. A similar theory, in which the unseen satellites release gases rather than particles, has been proposed by Thomas Van Flandern of the Naval Observatory in Washington, D.C., but it has failed to receive any significant support from other ring theorists.

The discovery of the first non-Saturnian rings had little effect on the search for other new ring systems. Proponents of a thorough search for a Jovian ring by the Voyager spacecraft encountered considerable opposition within the Voyager imaging team, even though the five Uranian rings were discovered 6 months before the Voyager spacecraft was launched. Those opposed to the search pointed out that widely accepted ring formation theory did not call for any rings around Jupiter. According to this reasoning, Jupiter was too hot early in its development to allow the formation of an icy ring, as apparently occurred around Saturn. In addition, any rocky ring material would have been swept into the planet by lingering gases.



A mosaic of the Jovian ring taken by Voyager 2 from the planet's nightside. The ring and upper atmosphere are revealed by the sunlight that they scatter in the forward direction. [*Source: NASA*]

"I pushed for it anyway," says Tobias Owen of the State University of New York at Stony Brook, a member of the imaging team. "We felt that a ring around Jupiter might not necessarily be like those around Saturn." In the end, Voyager 1 was programmed to search for a Saturn-like ring as it crossed Jupiter's equatorial plane. The search "was really for the sake of completeness," according to Bradford Smith of the University of Arizona, head of the imaging team. "If you're going to go that far, you might as well look for it even if you don't think it's probable." Even with the initial decision made, some search proponents reportedly felt the need to guard before the flyby against the deletion of their planned viewing activities. As one team member put it, those supporting the search sometimes got the impression that its purpose in the end was to finally demonstrate the absence of any Jovian rings rather than to find any new ones.

Expectations aside, Voyager 1 did indeed find a Jovian ring, just catching its outer edge as the spacecraft crossed the equatorial plane. A bit to the surprise of even those advocating the search, the ring is very near the location (1.8 Jovian radii) previously suggested for an undiscovered ring or satellite. Mario Acuña and Norman Ness of NASA's Goddard Space Flight Center in Greenbelt, Maryland, had made such a prediction on the basis of a gap in Jupiter's radiation belts observed by Pioneer before it headed for Saturn. They reasoned that known satellites had obviously carved out similar gaps by absorbing the radiation in the vicinity of their orbits. Therefore, an unexplained gap might indicate an undiscovered moon or ring.

With Voyager 1's discovery, Voyager 2 was reprogrammed to view the ring with the sun shining from behind the planet. Viewed in this scattered light, it could be seen that the bright, 800-kilometer-wide ring is flanked by dimmer bands on either side. To the outside, the brightness dims rapidly into a long tail, but to the inside it decays more slowly, reaches a constant intensity, and continues in toward the planet's cloud tops, according to Edward Danielson of Caltech. On the basis of a preliminary analysis of the scattered light at two wavelengths, he estimates that the ring particles doing the scattering have a mean size of 8 to 10 micrometers. This is extremely small compared to the centimeter-sized balls of ice thought to make up the bulk of Saturn's rings, but larger particles, which scatter light less efficiently, may also be present.

Because it contains small particles and has a broad expanse, the Jovian ring does appear to be quite unlike the rings of Saturn. Owen suggests that perhaps, unlike the particles in the Saturnian rings, none of those in the Jovian ring remain there long, but may be only passing through on their way to the planet. They might originate, Owen speculates, as interplanetary material swept up by Jupiter's powerful gravity, as impact debris from the moons Almathea and Io, or even as ejecta from the extraordinary sulfurous volcanoes of Io.

A further complication for planetary ring theory is the discovery of significant numbers of particles above and below the ring plane of Jupiter. What prevents these particles from falling into the ring is not clear, but Owen and Danielson have an idea. "There has to be a strong interaction," Danielson says, "between the ring particles, the strong radiation trapped near the planet, and Jupiter's magnetic field." If the radiation charged up the particles, then they could be jostled out of the ring plane by the magnetic field, which wobbles back and forth across the ring because the field is imperfectly aligned with the rotation axis.

By the time Pioneer arrived at Saturn, ring fever seemed to have struck. Pioneer had been aimed outside rather than inside the rings because ground-based observations indicated that a fourth ring, ring D, lay inside the three known rings (A, B, and C). The chance of Pioneer and centimeter-sized ring particles colliding at nearly 100,000 kilometers per hour seemed too great for an inside passage. A fifth ring, ring E, was thought to possibly exist outside the known rings, but the hazard of a fatal collision there seemed considerably less. Or so it appeared until about a week before the Saturn encounter. Then, John Wolfe of Ames Research Center, the Pioneer project scientist, was quoted as saying that Pioneer had only a 50-50 chance of surviving the ring plane crossing in the vicinity of the E ring.

What Wolfe meant, it turns out, was that so little was known about that area that anything could happen, but the gist of that never appeared in the daily press. Those few investigators who had studied the possible dangers, some of whom have published their conclusions, felt that the chances of Pioneer being destroyed were minimal.

The E ring did not smash Pioneer to smithereens. In fact, either the E ring is so faint that it could not be detected by Pioneer, or it does not exist. But instruments aboard the spacecraft did discover two rather unusual new rings. The imaging photopolarimeter, designed and operated by Tom Gehrels of the University of Arizona and his team, produced a picture of a new ring (the F ring) that is no more than 500 kilometers wide and is separated from the outer A ring by a gap dubbed the Pioneer gap. Being so narrow, the new F ring bears a suspicious resemblance to the Uranian rings. Moreover, the imaging team confirmed a previously suspected division between the B ring and the fainter C ring; they also found variations in brightness across the A ring and a surprising amount of material in the nearly empty Cassini division, according to Gehrels.

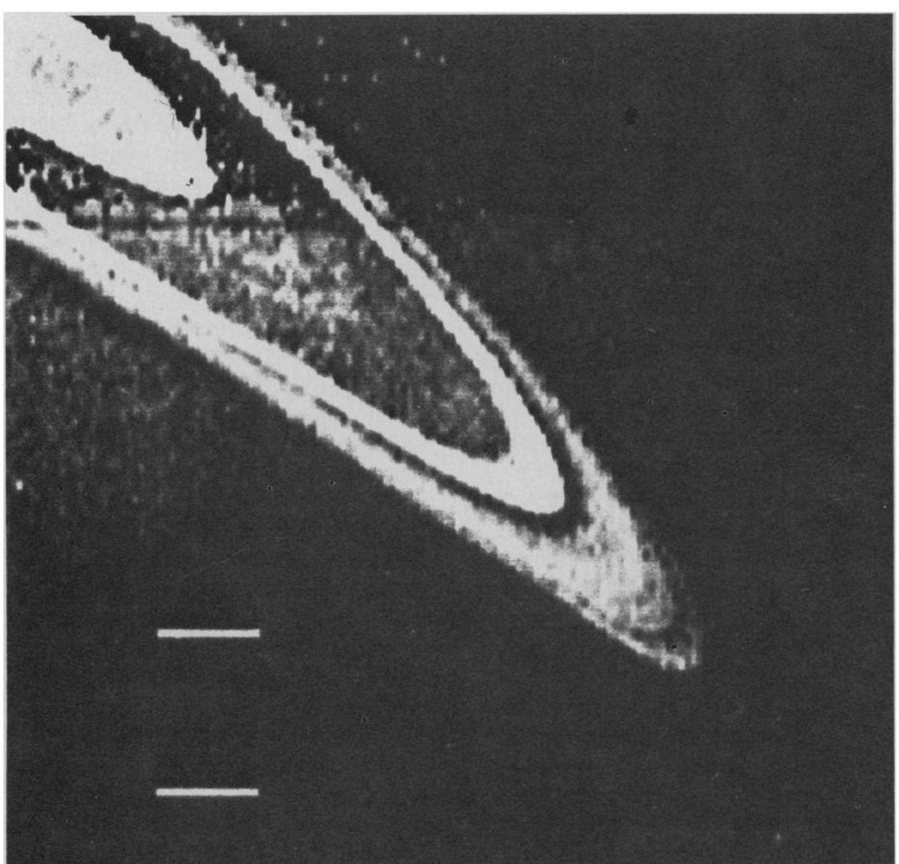
As if these discoveries did not provide enough new phenomena for ring theorists to mull over, James Trainor of Goddard Space Flight Center announced that Pioneer's cosmic ray detector indicated that a second new ring, the G ring, may lie five times farther out from Saturn than the A ring. Following the same general reasoning as Acuña and Ness used to predict the Jovian ring, Trainor suggests that the 300,000-kilometer-wide ring is responsible for the failure of cosmic-ray protons to rise to expected levels as Pioneer approached Saturn.

If such a ring exists, it would be an entirely new type because the proposed G ring lies well beyond the Roche limit. This is the distance from a planet inside of which a large body will be torn apart by the gravitational forces of the planet. Conventional thinking holds that rings form inside the Roche limit when material left over from the formation of the planet cannot form a moon or when a moon drifts inside the limit and is broken up.

The idea of a planetary ring outside the Roche limit of Saturn was actually put forward last year by Giuseppe Colombo of the Smithsonian Astrophysical Observatory. In fact, he drew an analogy between the wide gap between Mars and Jupiter, which is filled by the asteroid belt, and the similarly broad gap between the moons Rhea and Titan of Saturn. He concluded that Saturn might have an "asteroid belt" of its own. Ring G, falling in the gap between Rhea and Titan as it does, appears to fill the bill. If it formed in a way analogous to the asteroids, it may be the remnants of material that could not form into a moon because of gravitational disruption by Titan, the second largest moon in the solar system.

Planetary scientists will have a number of opportunities to view the rings discovered over the last few years during future flybys, occultations, and edge-on viewing perspectives from Earth. The question now on most people's minds is: How many rings remain undiscovered? Three years ago, Saturn was the "unique ringed planet." Today, it is Neptune that is, temporarily at least, unique among the giant gaseous planets in that it is not encircled by rings. If any are there, they might be detected on 10 February 1980, when Neptune occults a 10th-magnitude star. Although there are some concerns that Triton, the largest moon in the solar system, might have disrupted any rings Neptune ever had, the betting money says this planet has them.

—RICHARD A. KERR



The rings of Saturn as seen by Pioneer shortly before it reached the planet. Beginning beyond the apparent tip of the rings, the imaging photopolarimeter recorded the following: (i) a faint, as-yet-unidentified satellite (a small white speck); (ii) the newly discovered, narrow F ring, which is too faint to be reproduced here, but lies just beyond the bright outer A ring; (iii) the wide A ring itself; (iv) the Cassini division, a narrow, nearly empty band, seen here as a very bright band because of its particles' ability to scatter light forward that is shining through the division from behind; (v) the broader B ring, appearing dark here because it is dense enough to obstruct sunlight (most of the light seen in the B ring and on either side outside the rings is noise in the original data); and (vi) the C ring, which is thin enough to scatter light in the way the Cassini division does. The two parallel white bars are due to missing data [Source: NASA]