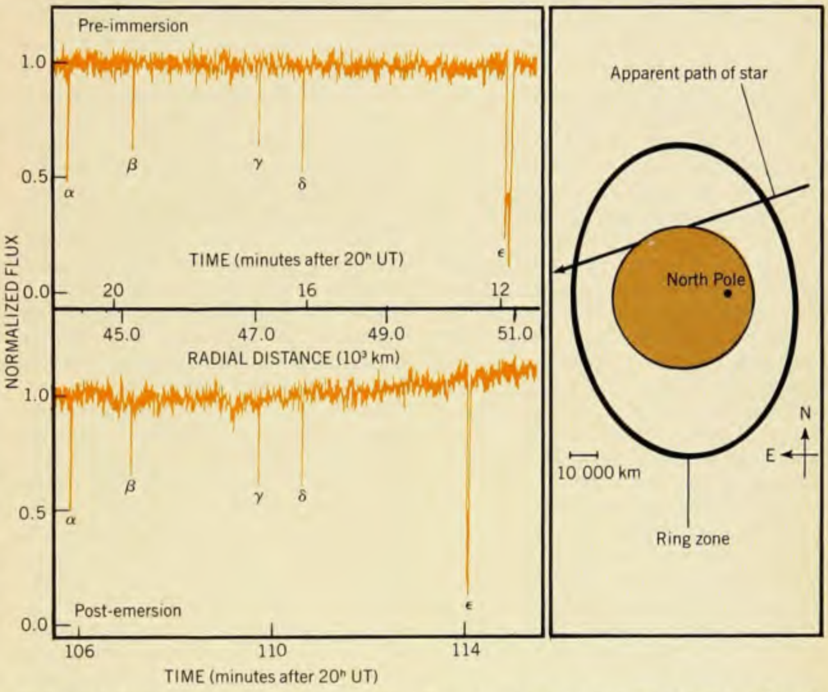
search & discovery

Occultation observations reveal ring system around Uranus

Much precise calculating and thorough planning went into preparations earlier this year for the first observed occultation of a star by the planet Uranus, but it was chance—and cautious allowance for chance—that led to the serendipitous discovery of five or more rings about the planet. Large uncertainties in the time at which the occultation would commence and in estimates of how far north it would be visible caused several observers to turn on their photometric equipment well in advance of the predicted moment—and only thus did they detect the unforeseen dips in the occulted star's light intensity that revealed Uranus as the second ringed planet in the solar system. Three groups promptly reported the unexpected dips, which they originally thought were caused by small Uranian satellites. James L. Elliot, Edward Dunham and Douglas Mink (Cornell University), aboard the flying Kuiper Airborne Observatory, saw brief occultations both before and after the star passed behind Uranus.[1] Robert L. Millis and Lawrence H. Wasserman (Lowell Observatory) and Peter V. Birch (Perth Observatory, Western Australia) have reported similar pre-immersion observations by Millis, Birch and Daniel Trout (Perth),[2] and J. C. Bhattacharyya and K. Kuppuswamy (Indian Institute of Astrophysics) at Kavalur, Madras, also reported a single event. The Cornell group was the first to suggest that the brief occultations were due to thin rings —not small satellites—because the time intervals between their pre-immersion and post-emersion events were nearly equal.



Detecting the rings. At left are the photometric tracings obtained by James Elliot's group at Cornell University during the pre-immersion and post-emersion periods; the existence of thin rings is implied by the symmetry of the events and by their narrowness. The star's light flux (normalized to 1.0 for full visibility) is plotted against time—the brightening of the morning sky caused the upward slope in the lower record. (Adapted from reference 1.) The figure at right shows the aspect of the ring zone as seen from Earth (North at top; East toward the left).

Confirmation of the rings. The existence of five rings—designated by Elliot, from the innermost out, as alpha, beta, gamma, delta and epsilon—is well established. Millis's data indicate the presence of two additional objects (possibly rings or satellites) inside the orbit of alpha, and a possible eighth ring ("zeta") beyond epsilon has been reported by Joseph Churms, who observed post-emersion occultations by alpha, beta and so on through zeta from Cape Town, South Africa. Confirmation also comes from Benjamin Zellner III (University of Arizona), whose data—obtained at Perth—show two occultations by alpha and one

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Will supergravity unify quantum theory with general relativity?

Recently some theorists have been trying to unify general relativity and quantum theory into a framework called "supergravity." The hope is that supergravity theory will provide a link between gravitation and particle physics. So far the work can be characterized as highly mathematical and limited to a relatively small group of practitioners. But enthusiasm among its proponents runs high.

Supersymmetry. Supergravity is an example of supersymmetry, which extends the Poincaré group as a symmetry of space-time by adding four new generators that behave as spinors; these generators vary as the square root of the translations, just as Dirac's equation is the square root of the Klein-Gordon equation. Supersymmetry is a global symmetry and is the first symmetry in particle physics that permits one to unify particles of different spin and statistics in the same multiplet. It was known previously that this unification could not be achieved within the usual mathematical framework for symmetries, namely Lie algebras. In supersymmetry, this problem is solved because the underlying framework is that of graded Lie algebras, in which both commutators and anticommutators occur.

The idea of supersymmetry was first introduced in 1971 by Yu. A. Golfand and *on Relativistic Astrophysics*, to be published in Ann. N.Y. Acad. Sci.

2. Yu. N. Gnedin, R. A. Sunyaev, Astrophys. and Space Sci. **19**, 61 (1974); M. M. Basko, R. A. Sunyaev, Astron. and Astrophys. **42**, 311 (1975).

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by beta, and from S. K. Gupta and H. S. Mahra at the Uttar Pradesh Observatory (Naini Tal). All the rings but epsilon might better be called ribbons, for the ring system of Uranus appears to consist mainly of gaps. Calculations by Brian G. Marsden (Smithsonian Astrophysical Observatory) yield radii of approximately 45 000 km for alpha and 52 000 km for epsilon, measured from the center of Uranus;[3] yet in this nearly 7000-km-wide belt, epsilon—the broadest of all detected rings—is estimated to have a width of only 50–100 km, and the others are much narrower.

In 1973 Gordon Taylor (Royal Greenwich Observatory) first predicted the occultation of SAO 158687, a ninth-magnitude red giant, by Uranus on 10 March 1977. It was hoped that light curves obtained as Uranus moved between the star and Earth would reveal information concerning the temperature, pressure and composition of the planet's atmosphere and provide a means to determine the diameter and oblateness precisely. The Cornell and Lowell groups, which had earlier cooperated on the observation of an occultation of the star Epsilon Geminorum by Mars,[4] began coordinating their efforts in 1976 to observe the Uranus event.

A flight into dawn. On the night of the occultation Elliot and his associates flew above 75% of Earth's atmosphere, on a course that would take them far south over the Indian Ocean, in a modified C-141 aircraft—the Kuiper Airborne Observatory—made available by NASA's Ames Research Center. With them the Cornell team carried a three-channel occultation photometer attached to the 91-cm KAO telescope. Three observation wavelengths—6190 Å, 7280 Å and 8520 Å—were selected to maximize the brightness of the star with respect to Uranus. About 40 minutes before the occultation by Uranus was expected, a sharp decrease in light intensity was observed for seven seconds, followed by four lesser ($\approx$1 sec) dips. After the 25-minute occultation by the planet, the pattern was repeated in reverse. The morning sky's brightness ended observations.

Meanwhile, at Perth, Millis and his collaborators, due to their geographic position, actually detected the first unexpected drop in signal level—lasting about eight seconds—some 70 seconds ahead of the Cornell team. Using a single-channel photometer in conjunction with Perth's 61-cm telescope, Millis had begun observing in the 8500-Å region almost an hour before the anticipated time for the occultation. The failure of a beamsplitter in Millis's photometer caused the team to miss both the delta and alpha rings, but they still recorded five events, counting the two between alpha and Uranus, before dawn; the shadow of Uranus itself passed south of Perth. Millis's record shows considerable detailed structure in his first-detected event (later to be known as the epsilon ring).

At Kavalur, despite predictions that the shadow of Uranus would miss India (it did), Bhattacharyya observed and recorded the Uranian events for 90 minutes using the observatory's 102-cm telescope. About 40 minutes before the occultation by Uranus he noted a dip of 53% in the star's brightness for about nine seconds; several more sharp spikes were recorded before the Indians lost sight of the planet. Bhattacharyya told us the major event seen at Kavalur was the epsilon occultation; it has since been reported that the weaker fluctuations he detected match with the alpha, beta, gamma and delta events recorded elsewhere.

When the first anomalous occultation was observed aboard the Kuiper aircraft, Elliot, still on the plane, contacted Marsden, who heads an international information clearinghouse for discoveries of transient astronomical phenomena. (Marsden put out a statement that same day that a previously unknown satellite of Uranus had been detected.) When the Kuiper plane landed in Australia around 9:30 in the morning Millis was there to meet it; Elliot's first words to his fellow observer as he stepped off the plane were "How many satellites did you see?". It was not until he was back at Cornell that Elliot unrolled his chart record and found the correlations between pre-immersion and post-emersion occultations that spelled rings.

The rings take shape. The very brief duration of occultations by the ribbons indicates that they have widths of only a few kilometers; Uranus's shadow crossed Earth's surface at about 12 km sec^{-1}, so Elliot estimates the narrow rings are only 12 km wide. On the same basis, he has determined a width of approximately 85 km for the immersion section of epsilon and 35 km for its emersion section. Epsilon must therefore either be elliptical or inclined to the plane of the other rings and satellites; it is also possible that portions of two incomplete rings were observed, rather than different chords of a single object. Marsden cites the Sun, Neptune and Uranus's satellites as possible sources of perturbations that would result in "imperfect" rings.

None of the rings were seen to obscure the star completely; Elliot saw an occultation of about 90% in the case of epsilon, while the light intensity was cut off by approximately 50% for alpha, beta, gamma and delta and by only 20% in the case of two events that correspond to Millis's inner objects. The implication is that the rings are composed of many small objects with diameters of less than four-to-six km, the projected diameter of SAO 158687 at Uranus. The maximum obscuration observed by Millis, in the epsilon ring, corresponds to an optical thickness of 2.3, about twice that of Saturn's B ring.

Many questions remain. The old science-fiction art that showed multitudes of ringed planets floating in space no longer looks quite so unrealistic in the light of the Uranus discovery. But if ringed systems are common in the universe, it is at least clear that they are not all alike. We asked Marsden why the rings of Uranus, in contrast with Saturn's, are so very narrow, with such wide gaps between them. He told us that resonances account for the gaps in the Saturnian rings; the famous Cassini's division, for instance, occurs because particles orbiting at that distance from Saturn would have exactly half the period of Mimas, the innermost confirmed moon—every two revolutions such particles would find themselves in the same orientation with respect to Mimas and would tend to be pulled out of place. Such resonances can sometimes produce *enhancements* of particle density as well—thus, perhaps, are thin rings formed.

Uranus's ring system, according to Marsden, may be a relatively new object in comparison to the age of the solar system, and it may—especially in the case of epsilon—be unstable in the long term. However, "things happen slowly out there," in Marsden's words, and the rings should certainly last long enough to check on them another time. A search has already begun with the object of locating other, fainter stars whose paths may be crossed in the future by Uranus, its ring system . . . or Neptune. An observed occultation by Neptune nine years ago revealed no rings. —FCB

References

1. Elliot, J. L., Dunham, E., and Mink, D. *Nature* (paper submitted in March 1977).
2. Millis, R. L., Wasserman, L. H., and Birch, P. V. *Nature* (paper submitted in March 1977).
3. *IAU Circular No. 3061* (1977).
4. Elliot, J. L., French, R. G., Dunham, E., Gierasch, P. J., Veverka, J., Church, C., and Sagan, C. *Science* **195**, 485 (1977).

in brief

The Massachusetts Institute of Technology is building the Alcator C tokamak at a total cost of $6.4 million. The device will have a capability of reaching 140-kG magnetic fields. □