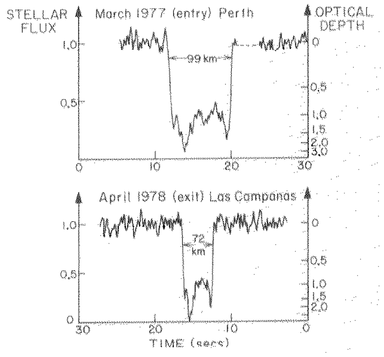
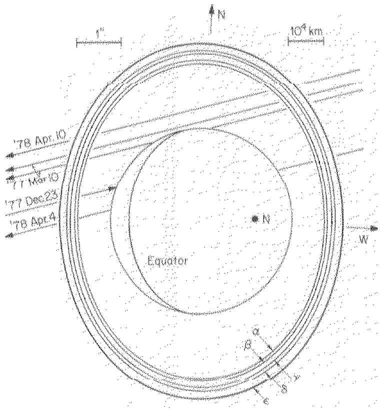
Research in Progress

Rings around the Planets



The epsilon ring is "seen" here before a star passes behind Uranus (top) and after (but different stars, different places, and different times) as the starlight is dimmed by the ring particles. Both figures show a bicuspid shape, but the varying width of the epsilon ring is evident. It is as narrow as 20 kilometers at another point.



Five of the nine narrow rings of Uranus are shown here (there are three more inside this set of rings and one in between), although the lines representing them are about 50 times too wide for correct scale. The paths of the occulted stars are indicated as well as the dates they were observed; initial discovery of the rings was on March 10, 1977.

Planetary rings are of interest because they probably represent an earlier stage of the evolutionary history of planets and their satellites. But because of a planet's tidal gravity, the particles that make up the rings haven't been able to accumulate into a satellite.

Rings around Saturn have been observed for centuries, but only in the last three years has it been discovered that two other planets — Jupiter and Uranus — share similar features. Voyager 1 detected Jupiter's rings in 1979, and rings around Uranus were found in 1977 quite by accident. Scientists from Cornell in the Kuiper Flying Observatory, studying Uranus when a particularly bright star passed behind it (a rare event), noted that the starlight also dimmed up to 90 percent several times before and after it was occulted by the planet.

With this obvious evidence of rings, Peter Goldreich, professor of planetary science and astronomy, and others at Caltech interested in planetary rings, were too impatient to wait 20 years for another bright star (Uranus is 100 times brighter than a typical star) to be in the right place.

Fortunately, a breakthrough in observational technique shortened the wait. Former graduate student Jay Elias realized that, because the planet's atmosphere contains a large amount of methane, which absorbs light at longer wavelengths, Uranus would be extremely dark when observed at wavelengths of two microns; conveniently, many stars are red and appear brighter at long wavelengths. This realization has made it possible to gather occultation data from infrared observation of much fainter stars, which exist in relative abundance and find themselves behind Uranus a bit more often.

Once or twice a year, in fact. Caltech Scientist Keith Matthews has flown to Chile to use the 100-inch telescope at Las Campanas on these occasions, bringing back data that are yielding more and more detailed information about the rings. Some things are now known about the rings of Uranus, but there is plenty left for Goldreich, the theorist, to theorize about.

Nine rings have been observed so far. While Saturn's rings are bright, broad, and separated by narrow gaps, the rings of Uranus are dark, very narrow, and separated by wide spaces. The narrowest ring is only 2 or 3 kilometers wide, about 50,000 times greater in diameter than in width, and the widest varies from 20 to 100 kilometers. The widest ring, known as the epsilon ring, is also the outermost, and has the most eccentric orbit of the seven rings known to have elliptical orbits. The long axes of these ellipses precess 1 to 2 degrees per day, that is, the point of closest approach to the planet also orbits around it.

From the precession rate (as a function of distance) the gravitational flattening of Uranus can be derived. The mass of the rings can be calculated from the fact that they precess together, as a body; the calculated mass indicates that the rings are between 10 centimeters and 1 meter thick, probably only a single layer of particles, according to Goldreich. What the particles are made of is still unknown; they are as black as coal, unlike Saturn's ring particles, which are very bright and probably made of water ice.

What holds these narrow rings together? Goldreich thinks that there is a frictional interaction from pairs of satellites — one inside and one outside each ring. Because of the "perverse nature" of particles in orbit, the diffuse material of the ring gains angular momentum from the satellite closer to the planet; that is, it is pushed outward; the satellite on the outer boundary is balancing this force with an opposite push exerted in an inward direction.

Confirmation of the existence of such satellites will likely have to wait for a closer look. Voyager 1 is already providing clues from close-up views of Saturn's rings. If Voyager 1 performs all of its Saturn tasks up to par, Voyager 2 will be deflected to an orbit that is less optimal for Saturn but that will enable it to fly by Uranus in 1986. This should provide answers to some of the remaining questions about Uranus and its rings and either prove Goldreich's theories correct or send him searching for new ones. ☐

News of Neutrinos

Neutrinos and the question of whether they do or do not have mass have concerned physicists for years, the assumption being that they do not. No evidence of mass has been detected (until recently), but scientists have kept trying. The question suddenly erupted into public debate last spring with the announcement that research at the University of California at Irvine had shown that neutrinos oscillate; such oscillations are impossible if they are massless. Other scientists, including a group from Caltech, immediately challenged these results.

The Caltech researchers (Professor of Physics Felix Boehm, Research Associate Petr Vogel, Research Fellows Alan Hahn and Jean-Luc Vuilleumier, Senior Design Engineer Herbert Henrikson, and Heemin Kwon, whose PhD will be awarded in June of 1981), working with colleagues from the Technical University of Munich and the Institute for Nuclear Science in Grenoble, France, have also been trying to track the elusive neutrino through oscillations. Like the Irvine group, they have attempted to detect whether the electron neutrino oscillates to either of the other two forms — the muon neutrino or the tau neutrino.

Their detector system, consisting of alternate layers of two kinds of particle detectors — cells of "scintillation liquid" and a chamber full of an isotope of helium — took two years to build at Caltech and another year to test with the 57-megawatt reactor in Grenoble. The Grenoble experiment uses protons as targets to detect neutrinos (antineutrinos, actually), tracking the neutron and positron as reaction products of an antineutrino and a proton.

The Irvine experiment dealt with two reactions — a charged current reaction (antineutrino plus deuteron to two neutrons and a positron), which is sensitive to oscillations, and a neutral current reaction (antineutrino plus deuteron to neutron, proton, and antineutrino), which should not be affected by oscillations. Reportedly, the charged current reaction occurred only about 50 percent as often as the expected rate derived from the neutral current reaction, allowing the conclusion that the undetected neutrinos had oscillated into other forms.

The Grenoble experiment uses only one reaction, and in order to interpret it, the number of neutrinos that are really supposed to be emerging from the reactor must be known. If there are fewer than are expected, oscillations can be assumed. However, this expectation can only be predicted, and dependence on such predictions is a definite drawback of the Caltech effort. On the other hand, since the chosen reaction has an event rate more than 20 times greater than that of the deuteron reactions, it is easier to distinguish it from background events produced by cosmic rays. Also the information obtained is more complete because it is possible to measure not only the reaction event rate but also the positron energy. Changes in this energy spectrum would also indicate oscillations.

One set of calculations predicting the number of neutrinos emerging from the reactor was published last year by Brian Davis (PhD '80) along with Vogel and collaborators from the Hanford Engineering Development Laboratory. The Caltech-German-French experiments that began in Grenoble a year ago and have continued through the spring and summer have generated data indicating that the predicted number, according to Davis-Vogel, of neutrinos are emerging from the reactor core and that they also have the predicted energies. If the Davis-Vogel calculations are correct, the presence of oscillations has not been proved.

Another recently published theory, however, predicts a 30 percent higher spectrum of expected neutrinos; the difference probably is due to different nuclear model assumptions used to calculate the unknown short-lived beta decay. If this higher spectrum is correct, it might alter interpretation of experimental results.

But independent evidence obtained this past summer tends to support Davis-Vogel. An experiment at Grenoble measuring electrons (the same number of antineutrinos and electrons are generated from fission of uranium) produced a spectrum within 5 percent of the Davis-Vogel calculation. Similar results from Oak Ridge also seem to confirm this theory.

The final word on neutrinos is not yet in. The Caltech group's ultimate tests, independent of a calculated spectrum, are yet to be performed. After further testing of their detector at Grenoble, Boehm's group plans to move it to the 2,700-megawatt reactor at Gösgen, Switzerland. There they will measure the neutrinos emerging from the reactor core at several distances; if changes over distance are observed, they would have to be due to oscillations. The question of neutrinos' mass, and with it the key to a number of cosmological puzzles, may soon be answered definitively. ☐