celerator is that its the beam is already of good quality. None of the beam is thrown away, for example. Moreover, Los Alamos has recently constructed an advanced electron injector with a significantly increased brightness. The accelerator cannot be brighter than its source.

There is also an unfortunate trade-off between the efficiency of energy transfer from the electron beam to the laser wave and the gain. As the efficiency increases as a result of tapering, the gain achievable at a fixed beam brightness and undulator length drops, plainly putting a constraint on the maximum efficiency allowed before the laser shuts off. This constraint becomes increasingly severe as the wavelength decreases. For this reason, no one expects anything like a 40% energy transfer efficiency in the first Paladin experiment, which will use a new undulator that is 5 meters long. The paper by Fawley discussed a modest 2% efficiency with a mildly tapered undulator.

To boost the overall energy transfer efficiency back up to a useful value, the strategy that is being adopted is to use a very long undulator. Since the gain is proportional to the undulator length, more energy can be extracted from the beam in a long undulator without shutting off the laser. Fawley mentioned a follow-on Paladin experiment with a 25-meter-long undulator. A visible/near-infrared free electron laser amplifier may require an undulator many tens of meters in length.

There are other physics issues that arise at short wavelengths. Microwaves travel through a wave guide, so there is no difficulty in keeping the radiation from diverging away from the electron beam and limiting the energy transfer, but there are no wave guides for the shorter wavelength radiation. As it happens, a theoretically predicted effect known as optical guiding may provide a solution. In short, as calculated by Scharlemann, Sessler, and Jonathan Wurtele of the Massachusetts Institute of Technology and by Gerald Moore of the University of New Mexico, the interaction between the electron beam and the radiation wave can generate a lens-like effect that focuses the wave.

Results from both the Livermore Paladin and Boeing Aerospace–Spectra Technology visible oscillator experiments should be in during the coming year. When details will be published is quite another matter. ■

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ADDITIONAL READING

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Planetary Scientists Are Seeing the Unseeable

Scientists who gathered last November in Paris at the 18th annual meeting of the Division of Planetary Sciences of the American Astronomical Society learned just how innovative their colleagues could be in times of fiscal restraint. Some researchers reported on mapping the unseen surface of Pluto while others told of charting the interior of the moon Mimas using ordinary images of its surface. Another group piggybacked on a project run by galactic astronomers. Others argued against the advisability of the separate simultaneous sessions on comets and asteroids, seeing as how some asteroids may be comets in disguise.

More Clues to Asteroid–Dead Comet Connections

Planetary scientists reported on two more lines of evidence supporting the proposal that some asteroids of the inner solar system are actually burned out comets and not escapees from the asteroid belt. One group of researchers found that asteroids that have orbits suspiciously like those of comets also have the same color as comet nuclei. From another study, it appears that a cometary source for some asteroids would make sense of the abundance of inner solar system asteroids and their orbits.

William Hartmann of the Planetary Science Institute in Tucson and David Tholen and Dale Cruikshank of the University of Hawaii examined ten asteroids that others had proposed as possible burned out comets, ones that could no longer release the dust and gas typical of comets. These asteroids had been singled out because they have peculiar orbits. Comets of the inner solar system show less preference for orbiting near the orbital plane of the planets than asteroids. In addition to larger inclinations, comet orbits tend to be elongated and oriented in special relations to Jupiter, whose gravity can be responsible for keeping comets from escaping from the solar system after their arrival from orbits far beyond Pluto.

Another characteristic of burned-out comets, originally proposed by Hartmann and his colleagues, is a dark neutral or brownish black color. They found such colors in the outer asteroid belt, in the dust around comets, and apparently on the surface of nearly inactive comets. When spacecraft arrived at Halley's nucleus, it too was found to be coal black.

When Hartmann checked on the color of the ten asteroids with cometlike orbits, he found that all ten had cometlike colors, or at least the color typical of outer solar system objects. Among a control group of 13 asteroids having typical asteroidal orbits, only one was dark-colored. Thus, at least among the chosen examples, all asteroids that orbit like comets are colored like comets, and almost all asteroids that have typical asteroid orbits are not colored like comets.

George Wetherill of the Carnegie Institution of Washington reported that burned-out comets in the inner solar system would also help explain the number of asteroids there. Celestial mechanicians have always had a problem explaining the presence of the roughly 1000 asteroids larger than 1 kilometer thought to pass inside the orbit of Earth, called Apollo objects, and the several thousand asteroids presumed to pass inside the orbit of Mars, called Amor objects. Only recently had a second means been proposed of bringing them in from the asteroid belt lying between Mars and Jupiter. Wetherill recently modeled these two known mechanisms by which Jupiter's gravity, with or without the help of Mars' gravity, can send objects in the asteroid belt into Apollo or Amor orbits. The modeled mechanisms could support a population of 361 Apollo objects and 1430 Amor objects, he found.

That more or less explains for the first time a deficiency that dynamicists, for lack of more productive sources in the asteroid belt, had attributed to dead comets. But do dynamicists still need a cometary source? Wetherill thinks so, if only to provide an explanation of observed objects with orbits inclined 50° to 70° or elongated and passing inside Earth's orbit but also near Jupiter. As a test of the reasonableness of a cometary source, he takes Comet Encke as an example. It is in an Apollo-type orbit and looks to be a comet in its old age. It has probably been in its present orbit only some thousands of years and could expire in the astronomical near future. But Wetherill calculates that to account for the otherwise curious distribution of Apollo and Amor orbits there need be only one Encke-like comet brought in every 50,000 years. He cannot say how often that actually happens, but Encke's existence would suggest that it is often enough, he says.

Mysterious Pluto May Shrink No Longer

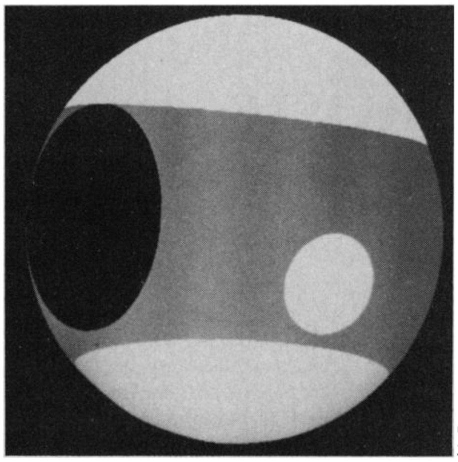
Pluto has been shrinking precipitously during recent decades, at least astronomers' best estimates of its size and mass have been, but the end seems to be in sight. Thanks to a recent series of eclipses involving Pluto and its satellite Charon, astronomers now believe that Pluto is small, smaller than seven satellites of other planets, and relatively dense, dense enough that rock rather than ice must contribute the bulk of its mass. The continuing eclipses are also allowing astronomers to begin mapping the surface of Pluto, a planet so remote that its relatively mammoth satellite went unnoticed until 1978.

David Tholen, Marc Buie, and Alex Storrs of the University of Hawaii and Neil Lark of the University of the Pacific reported at the meeting that they had set the most precise limits yet on the sizes of Pluto and its satellite on the basis of five usable eclipse events observed this year and one in 1985. It was in early 1985 that astronomers first caught sight of the two bodies alternately passing in front of each other, events that include transits, occultations, and eclipses but are lumped under the term eclipses or mutual events. The precise timing of such events, which occur for only a few years every 124 years as Earth, Charon, and Pluto line up, allows the calculation of Charon's orbital period, radii of the bodies, and the density of the planet-moon system.

Estimates of Pluto's size had been running on the high side even before the planet was discovered. Judging by its apparent gravitational effects on Neptune, before its 1930 discovery, Pluto's mass was assumed to be ten times that of Earth. By the early 1970s estimates of its mass had plummeted to a maximum of about 17% of the mass of Earth. After the 1978 discovery of Charon as a bulge on the side of Pluto's starlike photographic image, the orbital distance and period of revolution of Charon yielded a mass of about 0.2% of Earth's mass.

Pluto's supposed size shrank with its decreasing mass, but size estimates remained uncertain until the mutual events began. The Hawaii group's current best estimate is a radius of 1145 ± 46 kilometers for Pluto and 642 ± 34 kilometers for Charon. That makes the planet Pluto two-thirds the size of Earth's moon and indeed it would make a satellite of rather ordinary size if it orbited Jupiter or Saturn. As some consolation, Pluto is still twice the size of the largest asteroid. And having a moon half its own size makes it unique in the solar system.

The sizes of Pluto and Charon plus the mass of this system yield a mean density of 1.84 ± 0.19 grams per cubic centimeter (a 1 sigma error). Some researchers had suggested that Pluto is all water ice (density 1 gram per cubic centimeter) or even all methane ice (density 0.5 gram per cubic centimeter). Obviously, the system contains some rock. If one assumes the above calculated density, a reasonable density for the rock, and uncompressed water ice, rock would account for far more than half of the mass of the system. Any indication of the composition of the Pluto-Charon system is of great interest in that many astronomers suspect that it is not so much a planet and its satellite as a remnant of the debris that agglomerated to form true planets.


M. Buie

The invisible face of Pluto. *This computer-modeled map of reflectivity variations on Pluto is based on brightness variations observed during the past few decades. North is at the top.*

Mutual events of the Pluto-Charon system are also being used to determine the brightness and color variations across Pluto's surface, a surface that is so remote that when seen through even the largest telescopes it shrinks into a single point of light. By recording through different color filters the way the total brightness of the system varies as one body progressively blocks the other, the Hawaii group found that the blocked portion of Pluto has a relatively high reflectivity of 0.61 and the blocked portion of Charon has a lower although still reasonably bright reflectivity of 0.42. The side of Charon facing Pluto (but not the other side) has a neutral color in contrast to Pluto's slight reddish tinge.

Buie and Tholen have combined information from the mutual events with longer term brightness variations to form a map of the unseen surface of Pluto. The additional variations used are the 6.4-day variation caused by Pluto's rotation, the amplitude of which has been increasing during recent decades, and a dimming of the planet as its motion along its orbit has changed the viewing perspective from Earth. Buie and Tholen first assumed that the surface patterns of brightness responsible for the variations are circular and that Charon's contribution is constant. Then they added two bright polar caps to an older, two-spot model to create the long-term dimming.

After 40 hours of Cray X-MP/48 supercomputer time to achieve the best fit of the model to the observations, there were two large, blindingly bright polar caps, an equally bright but small equatorial spot, and a larger pitch-black equatorial spot. The unrealistic brightness contrast of the model might be avoided, says Buie, if the north polar cap is receding as spring begins there.

Astronomers are applying similar if less complex modeling to the mapping of asteroid surfaces. In the case of Pluto, even the Space Telescope will not give a final answer. It will be up to observers of the mutual events of the next few years, events that will progressively cover more of the two bodies.

IRAS Puts Astronomers Out of (One) Business

The Infrared Astronomical Satellite (IRAS) has produced a windfall for solar system astronomers despite its primary mission as the mapper of galactic infrared sources. At the meeting Dennis Matson of the Jet Propulsion Laboratory and his colleagues reported that IRAS had performed "the largest, most uniform and least biased survey ever conducted for asteroids and comets." Of the more than 3300 known asteroids, IRAS provided infrared emission measurements of 1811 of them at one or more wavelengths between 12 and 100 micrometers. About a dozen astronomers had been adding about 50 asteroids per year to the current list of roughly 200 that had been observed at 10 and 20 micrometers. But that effort was only getting harder as fainter and fainter objects remained.

The just-released IRAS data relieve astronomers of a career's worth of asteroid infrared radiometry survey work, but even at first glance the new results look interesting enough to occupy specialists for some time. Infrared emission measurements allow the calculation of asteroid sizes and reflectivity or albedo. Without such measurements, sizes remain unknown unless an albedo is assigned on the basis of the asteroid's color. The IRAS observations show that no single albedo can be assigned to a given color; there is actually a continuous spread of albedos.

Those working with IRAS data have already reported the first detection of faint dust bands possibly produced by collisions in the asteroid belt as well as dust trails left by known and unknown comets. Next comes a distillation of 35,618 sightings of unknown asteroids.

From Its Shape, A Look Inside Mimas

Mimas, the small inner satellite of Saturn, is the first planetary satellite other than Earth's moon to have its inner structure probed. It is not a uniform ball of ice and rock, according to Stanley Dermott and Peter Thomas of Cornell University. At some time it apparently separated into a relatively small, probably rocky core and a thick mantle of water ice. That such a small planetary body could manage to become differentiated into core and mantle may help explain how moons and planets form in the first place.

Dermott and Thomas probed the interior of Mimas by simply measuring its shape as recorded by the Voyager spacecraft. By locating the edges of the 400-kilometer moon to accuracies of 0.5 to 2 kilometers in various images, they found that it has a triaxial ellipsoid shape, a less extreme version of the shape of a slightly squashed football. Most crucially for their purpose, the relative lengths of the three axes showed that Mimas is not so small or so strong that it could effectively resist the gravity-induced tidal forces of Saturn and those of its own rotation that create the triaxial ellipsoid.

Given that Mimas does respond like a fluid to the forces shaping it, Dermott and Thomas could compare its actual shape to that predicted for a body that is uniform throughout. Mimas, it turns out, is not quite as squashed as it would be if it were homogeneous. Instead of a difference between its longest and shortest axes of 20.3 ± 0.3 kilometers, Mimas has a difference of 17.0 ± 0.7 kilometers. The conclusion is that Mimas is not uniform throughout but has subdivisions of differing density and thus composition.

Knowing that moons in the outer solar system are composed of ice and rock, Dermott and Thomas used the moment of inertia, also called the rotational inertia, calculated from Mimas's shape and the mean density calculated from earlier estimates of Mimas's mass to constrain a model of a moon with a rocky core. They found that it could have only a small core, one less than 200 kilometers in diameter and containing 14 to 28% of the mass of the satellite. The ice mantle in this model must have a mean density of about 1 gram per cubic centimeter or less, which is consistent with the density of uncompressed water ice.

Because the rock and ice of Mimas started out as thoroughly mixed dust and gas, the two must have become separated at some point. In the case of Earth, the separation presumably came after rocky debris had completely accreted to form the planet and radiogenic heat, compression, and the heat generated by impacts during accretion formed molten iron, which sank to form a core. Dermott and Thomas speculate that, in light of the weak heating expected within Mimas, the separation of the rock to form a core may have occurred as the first step of accretion. Dragged down by the enveloping gas, rocky debris could have formed a planetesimal onto which ice later accreted as the second stage of a two-stage, heterogeneous process.

This technique of shape analysis may be applied to at least one other case, Uranus's innermost major moon Miranda. A patchwork of oddly sculpted dark and light areas, Miranda may have frozen in mid-differentiation after a huge impact broke its light-colored mantle and dark core into pieces. At the meeting Merton Davies and his colleagues at the Rand Corporation and Thomas reported preliminary measurements that suggest Miranda too is a triaxial ellipsoid in hydrostatic equilibrium. Whether it too has a core could help decide among competing theories of its formation. ■

RICHARD A. KERR

Rice Plants Regenerated From Protoplasts

The ability to regenerate rice protoplasts means that for the first time a major cereal will become subject to modern biotechnological methods

THE major cereals are the mainstays of the world's food supply and therefore prime targets for efforts aimed at improving crop yields and hardiness. Nevertheless, these plants, which include rice, corn, and wheat, have so far not shared in the current flowering of plant biotechnology research. A major barrier preventing the application of modern biotechnological methods to cereal improvement has been the long-standing inability to find ways of regenerating the whole plants from the denuded cells known as protoplasts.

That barrier now appears to be falling as groups in England, France, and Japan are reporting success in rice protoplast regeneration. "It is clearly an important breakthrough in that it is the first of the major cereals for which this has been accomplished," says Gary Toenniessen, who oversees the Rockefeller Foundation's program on rice biotechnology research. The achievement opens the way to introducing desirable new traits into rice by direct gene transfer or by "protoplast fusion," which is a nonsexual way of producing hybrid plants.

The most recent and detailed report of rice protoplast regeneration comes from Edward Cocking, John Thompson, and Ruslan Abdullah of the University of Nottingham, England, who describe their results in the December issue of *Biotechnology*. In addition, M. Y. Coulibaly and Y. Demarly at the Université de Paris-Sud in Orsay, and at least four groups in Japan have been able to recover whole plants from rice protoplasts. The Japanese groups are those of T. Fujimara at the Mitsui-Toatsu Chemicals, Inc., in Kanagawa, who published the first report in 1985; Y. Yamada at Kyoto University; K. Shimamoto at Plantech Research Institute in Yokohama; and K. Toriyama at Tohoku University in Sendai.

Protoplasts of the monocotyledonous subclass of plants, which include the cereals, have generally been much more difficult to regenerate than protoplasts of the other major plant subclass, the dicots, which in-