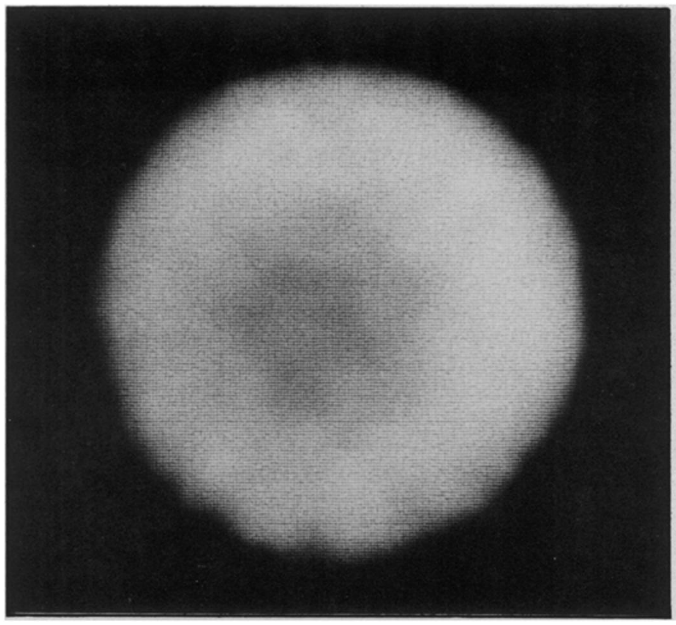
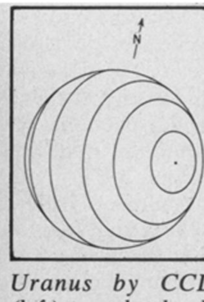
The CCD: New Eye on the Sky

A silicon chip the size of a dime has added 4,000 kilometers to the size of a planet

BY JONATHAN EBERHART





Bradford Smith/Univ. of Arizona

Uranus by CCD (left) reveals clouds of methane ice, including concentration near pole (right part of photo). Grid (above) shows photo's orientation.

One of the most promising and versatile new components on the front lines of electronics research is the charge-coupled device, or CCD. Though still in its infancy, the tiny chip is already being developed toward diverse applications ranging from data-processing to spacecraft navigation, to cannon shells that transmit pictures of their targets before they hit. One of the latest fields to join the list of beneficiaries is astronomy, and the first CCD instrument to get inside an observatory—an instrument not even designed for the purpose—has already proven its worth: The planet Uranus, the device's data have indicated, is some 4,000 kilometers larger in diameter than formerly believed.

The basic CCD concept is less than eight years old, according to David F. Barbe of the U.S. Naval Research Laboratory. "The charge-coupled device," he says, "operates on the simple principle that [electric] charge can be collected in potential wells much like rain is collected in buckets. If a two-dimensional array of potential wells is formed, and if a scene is imaged on the array, then charge will collect in the wells in proportion to the incident light intensity." The pattern formed by the differing charges is read out by—to pursue the bucket analogy—sequentially emptying the buckets in one row through an "output port," then shifting the remaining rows over one step so that the next row is lined up with the port and repeating the procedure, and so on for all the rows.

As used in an observatory, the CCD is the heart of a camera, taking the place of a more conventional electronic imaging device such as a vidicon. Last year, a CCD camera was designed by James Janesick of the Advanced Imaging Development Group at Jet Propulsion Laboratory in Pasadena and built primarily as a laboratory version to check out the system's performance. Though obviously only a first step (the related electronics filled two standard rack panels and had to be moved in a half-ton truck), it so intrigued astronomer Bradford Smith of the University of Arizona that he arranged for it to be temporarily installed on the 61-inch telescope at the university's Mt. Lemmon Observatory near Tucson.

The CCD chip itself was one developed by Texas Instruments, providing a 400-by-400 array of light-gathering areas or picture elements, known as "pixels" (the waterbuckets), all on a silicon wafer no larger than a dime and perhaps a tenth the thickness of a human hair. When Smith aimed the telescope at his chosen target, the resulting image was only about 20 pixels wide, representing about 4 seconds of arc, yet this fledgling effort has already added to knowledge of the subject.

The subject was Uranus, seventh most distant planet from the sun and tilted so radically that its axis of rotation lies almost in the plane of the ecliptic. And Uranus, judged by the CCD image, is about 4,000 kilometers larger in diameter than it was formerly thought to be.

The discovery is directly attributable to the CCD. The planet's atmosphere, mostly hydrogen and helium, contains about 1 percent of methane gas, which absorbs light at several characteristic wavelengths, including 8,860 angstroms. A conventional image of the planet made at that wavelength appears darker at the edges. This phenomenon is appropriately known as "limb-darkening," because the sunlight reflected to earth from the limb has passed through more "absorbers" (the methane molecules) than has sunlight reflected from the center of the disk. A limb-darkened image is thus a difficult one from which to measure diameter, since it is at its worst near the edge—right where the measurements have to be made.

The CCD, however, says Smith, is "200 times more sensitive than its nearest competitor" in the near-infrared portion of the spectrum around 1 micron (10,000 angstroms). This meant that when Smith photographed the planet through a filter centered at 8860 angstroms, thus blocking out the absorption band, it was possible to see a slight brightening that represented light reflected from thin, high-altitude clouds of frozen methane crystals, since the crystals lack the absorption band that gaseous methane has.

The result was a limb-*brightened* image instead of a limb-darkened one, since the edge of the disk has a greater concentration of these icy reflectors as well as of the gaseous absorbers. The brightening was extremely weak, says Smith, "like cigarette smoke illuminated against a dark background," but to the sensitive eye of the CCD it was nonetheless there, building up toward the limb until the limb itself—the key to measuring the planet's diameter—was clearly visible.

From that image (further refined by computer processing), Smith has calculated that Uranus has a radius of 27,900 kilometers ±500. The formerly best images, he says, were taken by the balloon-borne camera of the Stratoscope II program in 1972, but they were limb-darkened—and yielded a calculated radius of only 25,900 kilometers. So clear is the limb-brightened image that Smith was further able to measure the planet's oblateness: Its polar and equatorial radii are within 1 percent of each other.

The future of CCD astronomy looks bright indeed. The camera Smith used has recently been fitted to the 200-inch Hale telescope on Palomar Mountain (the size of its bulky electronics package has already been cut in half), and a greatly

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refined 800-by-800-pixel version will be sent into space as part of the 1981 Jupiter Orbiter-and-Probe mission. A simpler kind is being developed to help spacecraft more accurately track selected "reference stars" for navigation; this is because the discreet imaging areas of a CCD also make it free of the geometric distortions that cause positional errors in the electron beams of conventional vidicons. Some astronomers are urging that a CCD camera be developed for use on the earth-orbiting Space Telescope.

But there are other advantages to a CCD besides sensitivity and positional accuracy, according to Frederick Landauer, supervisor of the JPL Advanced Imaging Development Group. At visible wavelengths, for example, a CCD may be two or three times more sensitive than competing vidicons, but more to the point is the fact that it offers a 20-to-25-fold advantage in reduced "noise." Multiplied together, these factors give a far greater edge in "noise equivalent exposure," and the lead, Landauer says, is growing.

An additional tempting thought is that CCD cameras may not always be confined to expensive spacecraft and major observatories. Smith and Landauer agree that the only tricky part in the whole camera is the CCD chip itself. If the chips become available in the future as off-the-shelf items, the related electronics could be built in almost any competent shop accustomed to working in such areas. A world of astronomers is waiting. □