IMAGING OF URANUS AND NEPTUNE

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ATMOSPHERES

Observations of the minute disks of Uranus and Neptune from the surface of the earth present a major challenge to any observatory site and require the most advanced techniques in optical imaging instrumentation. Less than 4 arcsec across, the disk of Uranus would fit within the Great Red Spot of Jupiter in the focal plane of a terrestrial telescope; the smaller disk of Neptune, less than 2.5 arcsec in diameter, is scarcely more than half again that of Ganymede, the largest of the Galilean satellites. At present, both planets are situated at far southerly declinations, making them even more difficult objects for Northern Hemisphere observatories.

Both Uranus and Neptune exhibit faint bluish-green disks, a consequence both of their great distance from the sun and of strong absorptions of the longer spectral wavelengths by methane in the atmosphere above their cloud tops. Visual observers (see, for example, Alexander, 1965) have occasionally depicted bands and other low-contrast markings on Uranus and Neptune, but these are certainly suspect. During the mid-1960's, C.W. Tombaugh and one of us (B.A.S.) made photographic composites of several dozen selected images of Uranus in both blue and red light; we were unable to see anything more than a featureless, limb-darkened disk. In 1970 the balloon-borne telescope, Stratoscope II, acquired several images of Uranus in visual light with a resolution of 0.2 arcsec (Danielson el al., 1972); although some investigators suggested evidence for

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vague, dusky markings, the cases presented were anything but convincing. Several attempts have been made recently to employ speckle image interferometry as a means for investigating the tiny disks of these distant planets. Although the prospects appear to be promising, no useful results have been obtained to date (R. Goody, 1981).

We conclude that the disks of Uranus and Neptune are probably featureless in visible light, i.e., they do not show the same type of banded, atmospheric structure which is so familiar a characteristic of the images of Jupiter and Saturn. This banded pattern, a result of strong zonal (east-west) currents in the atmospheres of these rapidly rotating planets, is made visible by the convective overturning of their atmospheres and the corresponding production of multi-hued condensibles at atmospheric levels which are observable in the visual region of the spectrum. The atmospheric circulation of Uranus and Neptune might well resemble that of Jupiter and Saturn, but the condensibles are either more homogeneous in their optical properties or, more likely, form at levels which are too deep to be seen in visible light.

During the mid-1970's, prototype versions of a new type of optical detector became available to the scientific community. This solid-state array detector is known as a charge-coupled device or CCD, and among its many superior characteristics are high quantum efficiency in the near infrared, coupled with very low readout noise. In April 1976 a 400x400-element CCD was placed at the Cassegrainian focus of the Catalina Station 154-cm reflector (University of Arizona Observatories) in a series of tests of its applicability for astronomical research (Smith, 1977). Included in a list of selected objects was the planet Uranus. Among the optical filters employed was one with a narrow transmission band centered on the 8900A absorption band of methane. The absorption within this band by methane in the Uranus atmosphere is so great that the average albedo over the disk of the planet is less than 0.02. The images, however, showed a non-uniform disk with pronounced limb brightening, which tended to be stronger toward the

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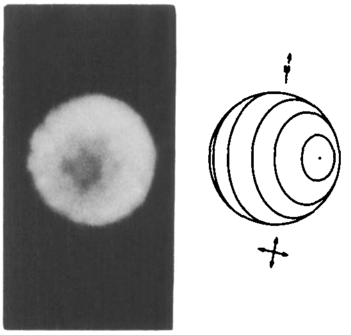

Fig. 1. CCD image of Uranus in the 8900A methane band taken in 1976.

north polar regions (Fig. 1). Although this early CCD had a relatively high level of read-out noise, the non-uniformity of brightness over the 3.9 arcsec disk is readily apparent. The limb brightening must be due to an optically thin layer of particulates at such great height in the Uranus atmosphere that back-scattering occurs before individual photons can be absorbed by atmospheric methane. Because the background of the methane-absorbing atmosphere of Uranus is so dark, hazes of extremely low optical thickness can be detected. Candidate materials for the high, optically thin haze include methane ice crystals, photochemically produced organic particulates and dust of exogenic origin. The relative infrequency with which superior image quality occurs at even a good site has thus far prevented us from obtaining the time coverage necessary to look for rotational effects. However, the possibility remains for an observer with dedicated instrumentation and ample observing time at a good site.

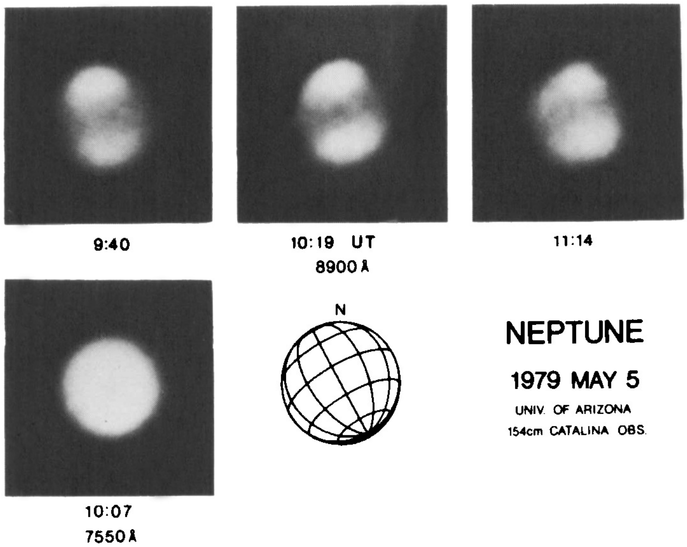

Fig. 2. CCD images of Neptune in the 8900A methane band and continuum (7550A).

In May 1979, with a better CCD and better image quality at the same telescope, we observed Neptune through a set of filters centered on various methane absorption bands from 7260A to 1 micron (Smith el al., 1979). Selected images can be seen in Fig 2. As with Uranus, a non-uniform disk is apparent, but the appearance of Neptune is quite different from that of its inner neighbor. The southern hemisphere shows a general brightening; the northern mid-latitudes, however, contain a non-axisymmetric bright feature which is observed to move eastward with the planet's direct rotation. The shape of the 2.5 arcsec disk has been distorted by contrast enhancement in the computer processing of the images. One year later, these features appeared to be less conspicuous. Whether this difference is a result of real changes in the planet's atmosphere or merely that of looking at a different longitude is not known.

We are continuing to work with the methane-band images of Uranus and Neptune. Image restoration techniques are being applied in an effort to remove the smearing effects of the terrestrial atmosphere and the instrumentally induced point-spread function.

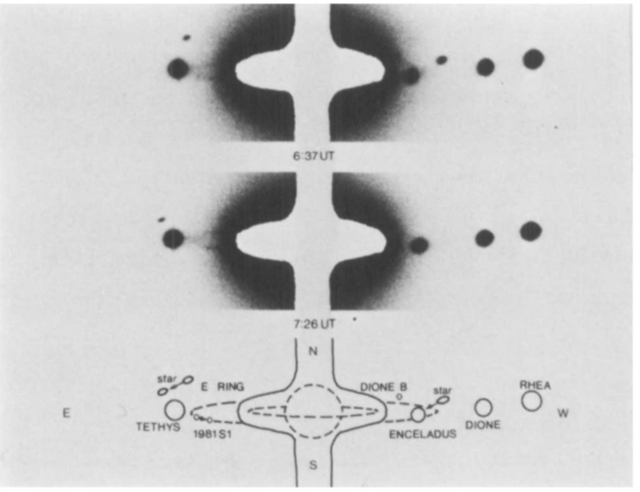

Fig. 3. Photographs of Saturn's E ring and satellites taken with the coronagraph on 1 April 1981.

Success with these image processing techniques could lead to better limb-brightening profiles, determination of the areal distribution of hazes and a rotation period for Neptune.

SATELLITES AND RINGS

The remoteness of Uranus and Neptune adds to the difficulty of observing objects very close to them, such as rings and satellites with small orbital radii. Scattered light from the relatively bright planetary disks spills over into the region of interest, i.e. the nearby space within a few planetary radii of their respective centers. However, scattered light caused by instrumental diffraction can be removed by a device called a focal-plane coronagraph - a modification of a technique developed by Lyot (1939). To illustrate the capability of this device and to emphasize that, even in this era of exploration by planetary spacecraft, there are still important observations to be done from the ground, Fig 3 shows recent observations of the E ring and a new satellite of Saturn made with our focal-plane coronagraph and a

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more classical detector - the photographic emulsion (Larson *et al.,* 1981). The focal-plane coronagraph thus has a demonstrated capability for overcoming the long-standing problem of trying to study faint objects which are located close to bright ones (Larson and Reitsema, 1979).

The focal-plane coronagraph, when used together with a CCD, can be applied to the search for close-in satellites of Uranus and Neptune and to make optical observations of the known rings of Uranus.

OBSERVATIONS FROM SPACE

As presently scheduled, Space Telescope will be placed in orbit in January 1985 and will shortly thereafter begin imaging observations of Uranus and Neptune. The maximum resolution of the Wide Field/Planetary Camera, employing multiple imaging and image-restoration techniques, is about 40 km/au. For mean-opposition distances of Uranus and Neptune, this becomes approximately 700 km and 1200 km respectively. The respective number of resolution elements across the disks would be 70 and 40. Thus, Space Telescope will enter a realm for which no previous experience exists.

Voyager 2 is now (September 1981) on its way to Uranus and will arrive at this remote planet on 24 January 1986. Imaging resolution of atmospheric features may be as high as 20 km, while for the satellites and rings resolution will be better than 5 km and, for a few satellites, as low as 1-2 km. If Voyager 2 manages to survive an additional 3.5 years in space, it will arrive at Neptune on 24 August 1989, twelve years to the day after its launch, obtaining images of that planet, its satellites (and rings?) with resolutions comparable to those at Uranus.

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