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NOTE

Ground-Based Observations of the Jovian Ring and Inner Satellites[1]

D. C. JEWITT,*,† G. E. DANIELSON,*,† AND R. J. TERRILE‡

*Division of Geological and Planetary Sciences, †Palomar Observatory, and, ‡Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91125

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Ground-based 0.9-μm observations of the Jovian ring and inner satellites are reported. The ring observations substantially confirm those obtained by the Voyager spacecraft. The first ground-based detection of 1979J2 suggests a geometric albedo of ~0.10 and a new value for its orbit period of 16 hr 11 min 23.5 ± 0.5 sec.

Introduction. The Jovian ring was first observed by the Voyager spacecraft during its close encounter with Jupiter (Smith *et al.*, 1979a). The properties of the ring have been reported by Jewitt and Danielson (1980). Ground-based observations in the infrared have been reported by Becklin and Wynn-Williams (1979) and by Neugebauer *et al.* (1981), and in the visual by Smith and Reitsema (1980). We report here ground-based observations of the ring and small inner satellites with the Hale 5-m telescope and a CCD.

Observations. Observations of the inner Jovian system were obtained with the Palomar 5-m telescope on UT 1980 March 5th. A Texas Instruments CCD was used at the prime focus, with the Prime Focus Universal Extragalactic Instrument (PFUEI) optical coupler giving an equivalent system focal ratio of $f/1.4$. The image scale on the 500 × 500-pixel CCD was 0.422 ± 0.001 arcsec per pixel. To minimize thermal noise the detector was cooled to 141°K.

In order to reduce the effects of scattered light from the bright face of the planet, a simple coronagraph was employed. A blackened aluminum occultation disk of 35-arcsec projected radius was found to produce optimum results (at the time of the observations, the Jovian equatorial radius subtended 22.3 arcsec). No attempt was made to occult the two Galilean satellites also present in the 211-arcsec-wide field. A further reduction of the scattered light was obtained by observing through a 150-Å-wide filter (FWHM) centered at 8870 Å. At this wavelength the light from the planet is suppressed by an intense methane absorption band.

Observations were secured in a 2-hr period beginning at UT 1980 March 05.39. The phase angle at the time of observation was 2.0° and the jovicentric latitudes of the Sun and Earth were −1.0 and −1.2°, respectively. With Jupiter hidden behind the coronagraph occulting disk, some 14 exposures of either 60, 300, or 500 sec duration were taken. Since the planet was hidden from view throughout each exposure, guiding was accomplished by using an offset guider centered on a field star. The planet moved ~1.5 arcsec relative to the field stars during the 300-sec exposures. This differential motion was uncorrected. Typical seeing disks were 1.2 to 2.0 arcsec (FWHM).

Data reduction was performed in the fashion described by Young *et al.* (1979), except that dark emission was neglected.

Results. The Jovian ring was recorded on all of the images taken with exposures of 60 sec and longer. In each case, the ring appears as a stubby faint line extending east and west of the planet. The ring is immersed in a steep gradient of light diffracted and scattered past the occulting disk. The ring signal typically amounts to only a few percent of the scattered light from the planet. Removal of the background was achieved by subtracting the average of the two strips of sky adjacent to the ring from the region of the ring. One example of a background subtracted image is presented in Fig. 2.

Due to the large size of the occulting disk and to the imperfect alignment between it and the center of the planet, six of the images show only one side or the other of the ring. Measurements of the eight images in which both ring ansae are simultaneously visible yield a value of the ring radius equal to 40.4 ± 0.2 arcsec or 1.81 ± 0.01 R_J. Because of smear and seeing-broadening, this must be regarded as an upper limit to the true radius. In an attempt to remove the seeing-broadening, the HWHM of the ring image (0.6 arcsec) may be subtracted from the above value, giving 1.78 ± 0.02 R_J as the ring radius.

From photometry of the 7.2 arcsec of the ring furthest from the planet, a mean flux density of 1.2 ± 0.1

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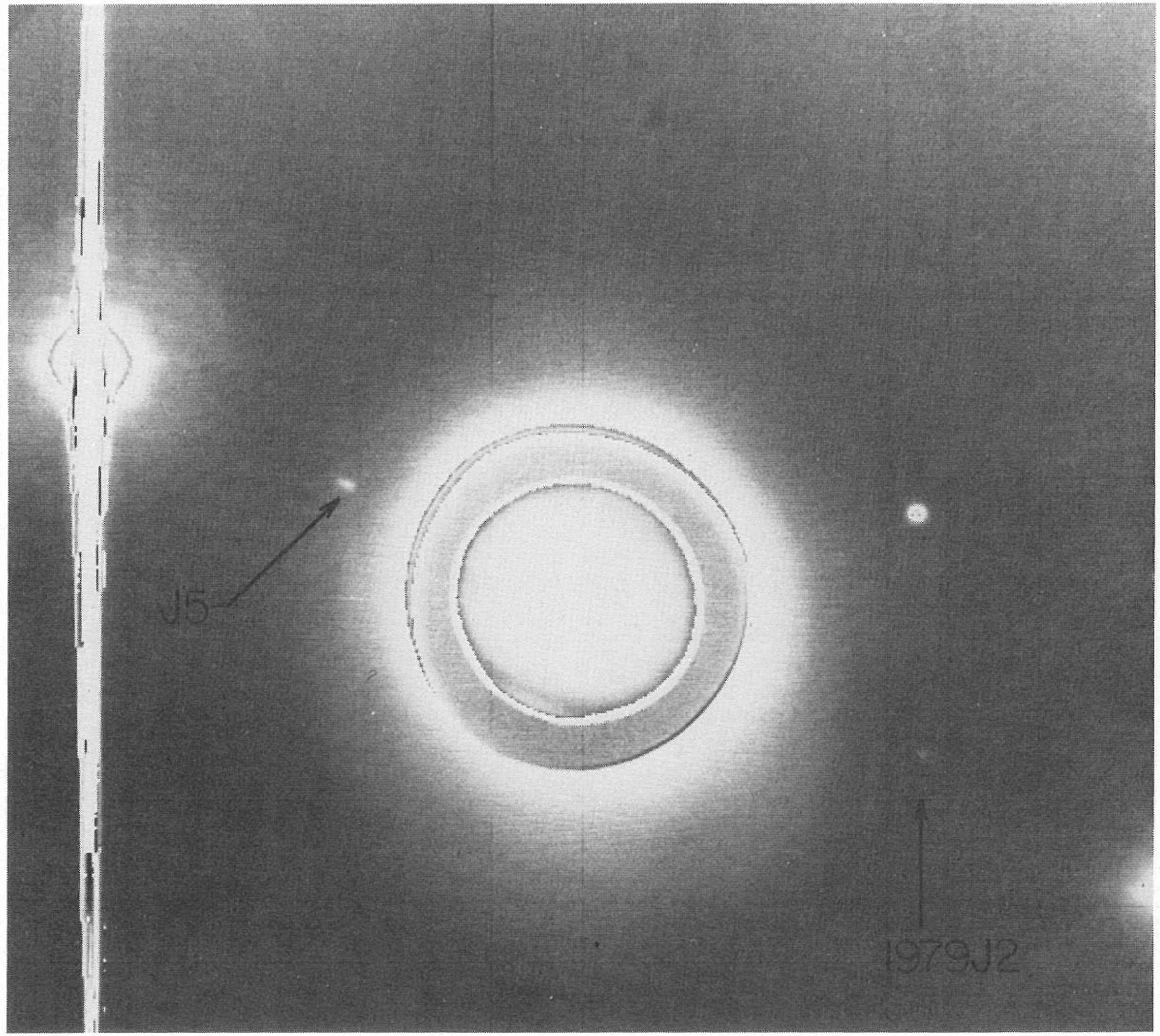

FIG. 1. A 300-sec exposure showing occultation disk, halo of scattered light, and satellites J5 (Amalthea) and 1979J2. An image of the disk of Jupiter has been digitally added for scale.

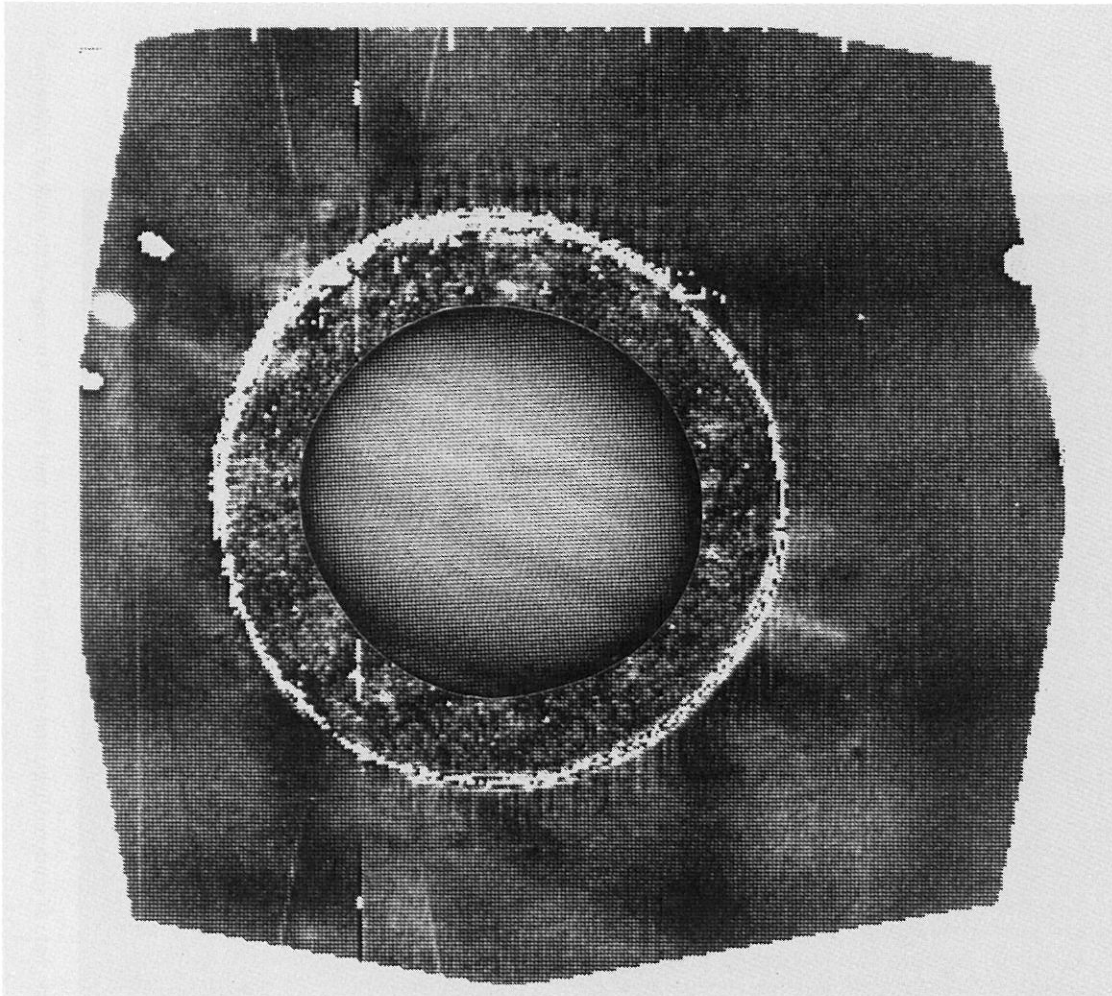

FIG. 2. Close-up of the ring. This frame has been low pass filtered by subtracting the average of two rotated versions of the original. Satellite Amalthea is visible at the extreme left.

$\times 10^{-30}$ W m^{-2} Hz^{-1} (arcsec)$^{-1}$ per ring arm at 8870 Å wavelength was determined. This corresponds to approximately 18 mag (arcsec)$^{-1}$ at this wavelength. The ring was not resolved in the north–south direction, implying that its projected thickness is much less than 1 arcsec. Thus a lower limit to the ring surface brightness of $1.2 \pm 0.1 \times 10^{-30}$ W m^{-2} Hz^{-1} (arcsec)$^{-2}$ per ring arm is established from the PFUEI data alone. The ring dimensions found from Voyager observations (Jewitt and Danielson, 1980), together with the measured flux density per unit length of ring, indicate a surface brightness of $\sim 1 \times 10^{-29}$ W m^{-2} Hz^{-1} (arcsec)$^{-2}$ per ring arm.

In addition to the ring, the pictures record the satellite J5 (Amalthea) and the recently discovered 1979J2 (Fig. 1). Amalthea was used to ratio the photometric properties of 1979J2. The ratio of the flux from 1979J2 to that from Amalthea was found to be 0.30 ± 0.01 (standard error on the mean of four measurements). Being only 1.3 magnitudes fainter than Amalthea, 1979J2 was an easy target in the pictures.

The position of 1979J2 relative to Jupiter was determined by using the ring to locate the apparent center of the planet. A least-squares fit to the data shows that the satellite reached eastern elongation at UT 1980 March 5.483 ± 0.002.

The images were carefully searched for evidence of the satellites 1979J1 and 1979J3 (Synnott, 1981). On the basis of data derived from Voyager images, it was estimated that these satellites should roughly double the apparent brightness of the ring in the pixels which included both a satellite and the ring. Three consecutive frames do in fact show a small bright object superimposed on the Jovian ring. The object is of about the brightness to be expected from 1979J1. However, owing to the short time base of the observations, it is not clear that the object moves as 1979J1 should. For this reason, we cannot yet claim to have detected either 1979J1 or 1979J3 in our data.

Discussion. The seeing-corrected value of the ring radius ($1.78 \pm 0.01\ R_J$) is slightly smaller than the value obtained from spacecraft imagery, $1.81 \pm 0.01\ R_J$ (Jewitt and Danielson, 1980). We believe the difference is partly due to the smear intrinsic to some of the Voyager images, which would tend to make the apparent ring radius larger than the true value. A contraction of order $0.01\ R_J$ is indeed consistent with the known amounts of smear in the Voyager data. Hence it is entirely possible that the satellite 1979J1 at $1.80 \pm 0.01\ R_J$ (Jewitt *et al.*, 1979) orbits slightly outside the ring as was originally believed.

The ratio of the brightness of the newly discovered satellite 1979J2 to that of Amalthea places a constraint on the albedo cross section product ($p\pi R^2$, where p is the geometric albedo and R is the equivalent spherical radius) of 1979J2. For Amalthea, $p \sim 0.05 \pm 0.01$ and $\pi R^2 \sim 3.3 \times 10^{10}$ m^2 (Smith *et al.* 1979a), giving $p\pi R^2 = 5 \times 10^8$ m^2 for 1979J2. If $R \sim 4 \times 10^4$ m is appropriate (Synnott, 1980), an albedo $p \sim 0.10 \pm 0.02$ is indicated for 1979J2. By this reckoning the surface of 1979J2 has an albedo twice that of Amalthea or 1979J1. However, this conclusion must be regarded as uncertain in view of the low reliability of the 1979J2 radius estimate.

Calculations by S. Synnott (private communication) predict eastern elongation of 1979J2 at UT 1980 March 5.497. The small but significant discrepancy between the observed and predicted times of eastern elongation (0.014 ± 0.002 day) may be used to further refine the orbit parameters of this satellite. The predicted position is based on Voyager observations taken approximately 1 year before the present observations. This may suggest that the reported period of 16 hr 11 min 21.25 ± 0.5 sec (Synnott, 1980) is short by about 2.2 sec (i.e., one part in 29,000). Alternatively, the eccentricity of the orbit may be nonzero.

Our observations provide upper limits to the brightness of any extra ring material not known from Voyager observations. By numerically generating thin artificial rings of various brightnesses, it was concluded that continuous ring material more than 0.1 times the brightness of the known ring (i.e., brighter than about 1.2×10^{-31} W m^{-2} Hz^{-1} (arcsec)$^{-1}$ per ring arm) would have been detected in the CCD frames. Likewise, small satellites between $1.8 < r(R_J) < 3.5$ with $p\pi R^2 \geq 2 \times 10^7$ m^2 would have been visible if they were not hidden by proximity to Jupiter. For dark bodies like Amalthea and 1979J1 with $p \sim 0.05$, satellites with $R \geq 11$ km would have been visible.

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