maize came into the Lake Pátzcuaro Basin, through tribute and through market exchange. Tzintzuntzan was the center of a tribute network that covered the entire Tarascan territory. Except from zones of unusual resources (such as near the copper and silver mines), a major item of tribute was maize. Maize was used for religious offerings and state gifts, and also to maintain the army and the king's household. The amount of maize obtained in this way was apparently insufficient to maintain the Lake Pátzcuaro Basin population, and residents are known to have traveled outside the basin to exchange lake products for maize (*5*). This exchange of maize for lake products demonstrates not only the need for maize from outside the basin but also indicates that a significant proportion of the maize exchanged in the Pátzcuaro markets of Tzintzuntzan and Pareo also must have come from outside the basin.

Tzintzuntzan was both administrative and market center for the Lake Pátzcuaro Basin. In wielding power not only on behalf of the city of Tzintzuntzan but more importantly on behalf of the Lake Pátzcuaro Basin, the governing elite developed and intensified Tzintzuntzan's centralizing political functions which they used in widening their economic and political base in the Tarascan kingdom. In the development of these functions, Tzintzuntzan differed from the florescent Aztec capital of Tenochtitlán, in part because of ecological differences between the Lake Pátzcuaro Basin and the Basin of Mexico. For these reasons, understanding the development of the Tarascan political system is important for understanding the evolution of state systems in Mesoamerica.

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13. This research was supported by the National Science Foundation (grant BNS 7609556) and the National Endowment for the Humanities (grant RO-25159-76-803). We also acknowledge the aid and cooperation of G. García Cantú, director of the Instituto Nacional de Antropología e Historia.

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Saturn's E Ring Revisited

Abstract. *Saturn's E ring is revealed by image processing of direct photographs of the 1966 edge-on presentation of the planet's ring plane. Two different techniques were used: scanning with an image quantizer operated in the derivative mode and computer-enhanced background subtraction from digitized images.*

The current edge-on presentation of Saturn's ring plane and the recent Pioneer 11 encounter have caused renewed interest in the E ring, which is external to the planet's visible rings. The existence of a ring extending to twice the diameter of the A ring was first reported by Feibelman (*1*) during the last edge-on passage (1966 to 1967). A somewhat similar report was given by Kuiper (*2*) in 1974. Originally called the D ring, and variously referred to in the literature as the D^1, E, or Z ring, it has now become established as the E ring.

The optical thickness of the E ring, derived from the 1966 Allegheny Observatory (University of Pittsburgh) photographs, was estimated by Smith *et al.* (*3*) to be 10^{-6} to 10^{-7}. Although the imaging photopolarimeter on the Pioneer 11 spacecraft did not detect the E ring directly because of its faintness, its existence was inferred from particle measurements (*4*), trapped radiation data (*5*), and magnetosphere measurements (*6*).

Because of the difficulty of presenting very faint images in halftone reproductions, the original photographs of the 1966 observations were never published, but microdensitometer scans derived from them were shown (*1*). Recently, two different methods of image processing were applied to the 1966 photographs in order to enhance the faint image of the E ring (Figs. 1 and 2). Figure 1A, a 30-second exposure taken on 27–28 October 1966, shows the visible rings edge-on; Fig. 1C, a 2-minute exposure taken on 14–15 November 1966, shows four satellites west of Saturn and two east of Saturn (additional satellites were photographed outside the field shown); and Fig. 1E shows a 30-minute exposure, also taken on 14–15 November. All prints were enlarged to the same scale. Figure 1, A, C, and E, shows $\times 5$ enlargements that were scanned 1 : 1 by means of a Tech/Ops image quantizer operated in the derivative mode to enhance edge contrast. The scanning aperture, referred to the original negative, was 25 by 25 μm (width and height). The resulting patterns are presented in Fig. 1, B to F. Figure 1G is identical to Fig. 1F, but was scanned in the reverse direction. In addition to the overexposed disk of the planet, a straight line is seen extending to the west of the planet on the 30-minute exposure taken on 14–15 November (Fig. 1, E to G). The line extends to roughly twice the diameter of the visible rings shown in Fig. 1A, and is interpreted as being the E ring.

The second method for image en-

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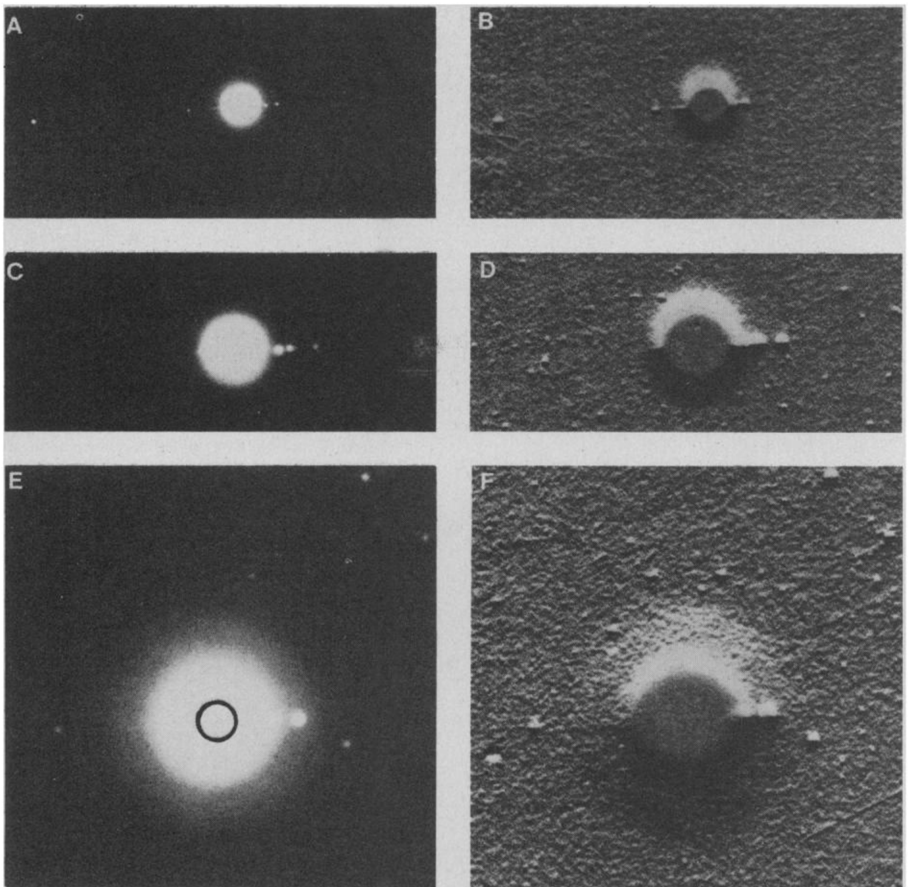

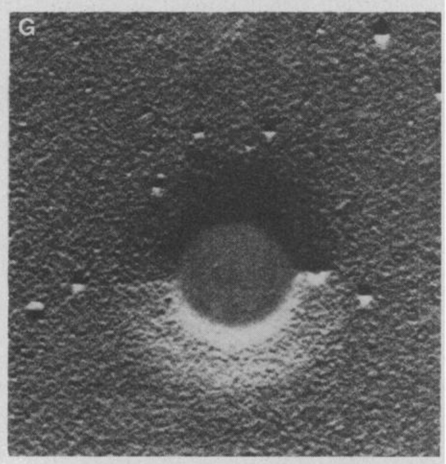

Fig. 1. (A) A 30-second exposure of Saturn taken on 27-28 October 1966. The planet is slightly overexposed and the visible rings are seen edge-on. (B) The same print as in (A), processed by the image quantizer in the derivative mode to enhance contrast. (C) A 2-minute exposure of Saturn taken on 14-15 November 1966. The planet is considerably overexposed, but four satellites are seen on the right (west) side. (D) The processed version of the image shown in (C). (E) A 30-minute exposure of Saturn taken on 14-15 November 1966. The planet is very overexposed. A very faint thin line can be seen to the left (east) side on the original. The superimposed circle represents the size of the planet's disk. (F) The processed version of the image shown in (E). The E ring is seen quite clearly extending to the east. (G) The same image as in (F), but scanned in the reverse direction. All images are printed to the same scale.

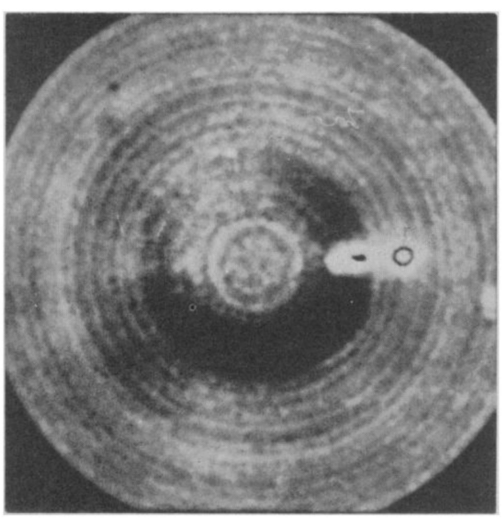

Fig. 2. Computer-generated image of the 30-minute exposure taken on November 14-15 1966; the circularly symmetric overexposed image of Saturn has been subtracted. The E ring is seen to the left (east) and satellites to the right. The vertical streak indicates where the digitized image was sampled for subtraction.

hancement was to subtract a circularly symmetric image of the overexposed disk of Saturn so that the resultant image revealed the E ring. The original negative of the 30-minute exposure for 14-15 November was digitized with a Photometric Data System microdensitometer in a raster scan mode with a 10-μm step and spot. The digitization was done in units of photographic density and no correction for the nonlinearity of the photographic emulsion was made. The digital image was displayed and manipulated with the Astronomical Data Analysis Facility image display system (*7*) of the Laboratory for Astronomy and Solar Physics. Since the overexposed disk of Saturn is almost circularly symmetric, a vertical slice was taken through the middle of the image and rotated about its axis of symmetry to create a second image, which was then subtracted from the original image. The result of this subtraction is shown in Fig. 2. The edge-on ringlike structure is seen in the left half of the image, tilted about 2.5° from the horizontal. The presence of the satellites in the right half of the image clearly shows the success of the technique in removing most of the circularly symmetric overexposed image of the disk of Saturn.

Coronagraph-type photographs made on 1 November 1979, microdensitometer tracings of them obtained at Pic du Midi by Dollfus (*8-10*), and photographic observations by Laques and Lecacheux (*11*) verify the existence of the E ring. Observations by Smith *et al.* (*12-14*), made with a charge-coupled device (CCD) camera in November 1979 and February 1980 at Catalina Mountain, Arizona, appear to confirm it unequivocally (*15*).

Note added in proof: The Space Telescope Wide-Field Camera Instrument Definition Team reports the detection of the E ring to at least 8 Saturn radii on both sides of the planet; a CCD camera was used at the U.S. Naval Observatory in March 1980 for these observations. (*15*).

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13. See CCD camera photographs by B. A. Smith, H. J. Reitsema, and S. M. Larsen [*Sci. News* **117** (No. 11), 167 (1980)].
14. See CCD camera photographs by B. A. Smith, H. J. Reitsema, S. M. Larsen, and J. Fountain [*Sky Telesc.* **59** (No. 4), 296 (1980)].
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16. At this writing, it is not clear why some of the early observations showed the E ring better on one side of the planet than on the other (*1*, *9*) but more recent data show it equally well on both sides (*9*, *10*, *12*). An illumination effect or uneven distribution of material in the ring could account for this.

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Energy Requirement for Nitrogen Fixation in Actinorhizal and Legume Root Nodules

Abstract. *The ratio of respiration to nitrogenase activity was measured in five species of actinorhizal root nodules and eight species of legume nodules. The two types of nodules could not be distinguished on the basis of this ratio; this evidence thus indicates that the energy cost of nitrogen fixation is similar for both.*

In order to evaluate the benefits of nitrogen fixation to higher plants, it is essential to know the amount of energy consumed in this process. Although there is increasing information about the energy requirement for nitrogen fixation in legume root nodules (*1*, *2*), as far as we know there have been no such studies of actinomycete-induced root nodules, which occur in eight families of dicots; the term "actinorhizal" is now being used for this association (*3*). Actinorhizal nodules are very different from legume nodules not only in the nature of the endophyte but also in other characteristics including anatomy, the lack of leghemoglobin, and higher partial pressures of oxygen in the region of the nodule containing the endophyte (*4*). Thus one would not necessarily expect the two kinds of nodules to be equally efficient in energy usage. Nevertheless, we have found that both the absolute rate of nitrogenase activity and the energy cost of nitrogen fixation are similar in the two types of nodules. This finding should give encouragement to efforts to develop new nitrogen-fixing plants, since it indicates that there is flexibility in the means of obtaining an efficient symbiosis.

We estimated the amount of energy consumed in nodules during nitrogen fixation in terms of the rate of CO_2 evolved from nodule respiration; nitrogenase activity was simultaneously measured in terms of the rate of C_2H_2 reduction (*5*). The ratio of CO_2 evolution to C_2H_2 evolution provides an estimate of the energy required for nitrogen fixation. Field populations of plants were examined so that a wide range of species could be studied and to avoid the abnormalities that are possible in greenhouse-grown plants. The rates of CO_2 and C_2H_2 evolution in these field-collected nodules were quite variable (Table 1), but there was no correlation with the type of endophyte, which confirms earlier reports (*6*, *7*). The ratio of CO_2 evolution to C_2H_4 evolution was much less variable, with values ranging from 3.4 to 5.6 for legume nodules and from 2.8 to 8.7 for actinorhizal nodules. If the higher ratios for *Ceanothus* and *Myrica* are disregarded (*8*), the range for actinorhizal nodules is from 2.8 to 3.8; if the value for *Melilotus* is disregarded, the range for legumes is from 3.4 to 4.5. Additional measurements will undoubtedly reveal lower ratios for the species studied, but the ratios are not likely to be much lower because the lowest values found approach theoretical limits (discussed below).

The values in Table 1 generally agree with earlier results for the energy requirement for nitrogen fixation by legume nodules (*1*). However, Pate and his co-workers have found values equivalent to 1.2 moles of CO_2 per mole of C_2H_2 reduced in both peas and cowpeas (*2*).

Detachment of root nodules, as done in our field measurements, may sometimes cause substantial reductions in nitrogenase activity (*9*). To test whether this could have any effect on our conclusions, we studied the effects of nodule detachment on CO_2 and C_2H_4 evolution by actinorhizal (*Alnus rubra*) and legume (*Glycine max*) nodules. Figures 1 and 2 show that for representative nodules excision has no effect on the ratio of CO_2 evolution to C_2H_4 evolution for the first 3 hours after excision, although there was a modest decrease in the absolute rate of CO_2 and C_2H_4 evolution by nodules of

Table 1. Results of measurements of nitrogenase activity (measured as C_2H_4 evolution) and CO_2 evolution in root nodules. Nodules were collected from the field between 19 and 30 August 1978, except as noted. Sites 1 and 2 were 1 mile apart. All collections were made in central Massachusetts. Nodules that were much larger or smaller than typical were excluded. Detached nodules (25 to 100 mg total) were placed in a 10-ml plastic syringe which contained a moist piece of filter paper, and the syringe was then capped with a rubber serum stopper. The assays were initiated (25 to 60 minutes after collection of the nodules in the field) by flushing the syringes with air and adding 10 percent C_2H_2. After incubating the nodules for 25 to 40 minutes at 22°C, gas samples were taken for analysis of CO_2 and C_2H_4 with a gas chromatograph (Carle model AGC 111) equipped with a thermal conductivity detector. The column (3.1 m by 1.7 mm, inside diameter) was packed with Porapak N, the carrier gas was helium, and the oven temperature was 40°C. Data are means ± standard errors of the mean; *N*, number of assays.

Species	*N*	C_2H_4 [μmole hour^{-1} g^{-1} (fresh weight)]	CO_2 [μmole hour^{-1} g^{-1} (fresh weight)]	CO_2/C_2H_4
		Actinomycete-induced nodules		
Alnus rugosa, site 1	7	12.1 ± 3.2	41.4 ± 7.8	3.4
Alnus rugosa, site 2	5	21.5 ± 1.9	80.9 ± 5.4	3.8
Ceanothus americanus	6	1.8 ± 0.1	15.8 ± 1.9	8.7
Ceanothus americanus, 4 September 1979	6	11.1 ± 1.8	42.0 ± 5.7	3.8
Comptonia peregrina	4	7.1 ± 0.7	21.2 ± 1.8	3.0
Elaeagnus umbellata	5	12.7 ± 0.9	35.9 ± 2.9	2.8
Myrica gale	4	6.1 ± 1.6	46.2 ± 6.0	7.6
Myrica gale, 3 July 1979	3	12.1 ± 2.3	42.4 ± 8.1	3.5
		Rhizobium-induced nodules		
Amphicarpa bracteata	5	9.5 ± 0.4	42.0 ± 3.4	4.4
Apios americana	5	10.4 ± 2.6	47.3 ± 6.9	4.5
Desmodium sp.	5	12.0 ± 0.7	41.4 ± 1.8	3.5
Melilotus sp.	8	5.8 ± 0.7	32.7 ± 4.6	5.6
Phaseolus vulgaris	5	13.1 ± 0.5	51.2 ± 2.7	4.0
Robinia pseudoacacia				
Nodules < 1 year old	4	9.8 ± 1.6	43.9 ± 6.1	4.4
Nodules > 1 year old	4	4.8 ± 0.6	20.9 ± 1.7	4.3
Trifolium pratense	2	25.7 ± 4.4	107.0 ± 19.0	4.2
Vicia sp.	4	23.2 ± 1.6	78.1 ± 5.3	3.4

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