ered from Voyager data (2), could be ruled out as the cause of the shadow because its greater velocity would have resulted in ~ 40 percent more motion relative to the atmosphere features than was observed.

A more detailed analysis of the two frames allowed a calculation of the orbital period as about 15 hours 45 minutes, and a search of Voyager wide-angle frames approximately 16 hours before the original shadow discovery revealed a frame (FDS 16363.45) containing images of both the satellite and its shadow (Fig. 4) in transit across the disk of Jupiter.

The satellite has now been observed in transit on images from both Voyager 1 and Voyager 2, and its period has been found to be 16 hours 11 minutes 21.25 seconds ± 0.5 second. The semimajor axis is 3.1054 Jupiter radii (R_J = 7.14 × 10^4 km). There is essentially no eccentricity information to date, but an inclination of approximately 1.25° has been determined. The profile observable when the satellite is in transit is roughly circular with a diameter of about 80 km. The limited data indicate that the albedo is similar to Amalthea's, that is, about 0.05.

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Brightness Temperatures of Saturn's Disk and Rings at 400 and 700 Micrometers

Abstract. *Saturn was observed in two broad submillimeter photometric bands with the rings nearly edge-on. The observed brightness temperatures fall below the predictions of atmospheric models constructed from data at shorter wavelenths, indicating the presence of an opacity source besides pressure-broadened hydrogen lines in the submillimeter region. In combination with earlier measurements at larger inclination angles, these results yield a 400-micrometer brightness temperature for the rings of ~ 75 K.*

Observations at wavelengths longer than 300 μm can provide tests of current theories of the atmospheres of the giant planets. Because opacities are reduced at longer wavelengths, such observations provide temperature measurements at deeper layers in the atmosphere. In the case of Saturn, however, these measurements are hampered by the unknown emission from the rings. At submillimeter wavelengths, current telescopes cannot clearly separate the rings from the disk. The earth's passages through the ring plane, which occur at ~ 14-year intervals, offer excellent opportunities to study the disk without interference from the rings.

We made submillimeter observations of Saturn in November 1979, when the inclination angle of the rings was only 1.2°. The observations were made at the 3-m NASA infrared telescope at Mauna Kea Observatory with the University of Chicago *f*/35 submillimeter photometer (1). We used a 55″ focal plane aperture and two filters with spectral passbands of 300 to 800 μm (mean wavelength $<\lambda> \sim 400$ μm) and 500 to 850 μm ($<\lambda> \sim 700$ μm). The filter passbands including the effects of atmospheric transmission are shown in (1). Mars was used for calibration with an assumed brightness temperature of 211 K (2). Errors due to atmospheric extinction were reduced by alternating measurements of Saturn and Mars. We made small corrections (≤ 4 percent) to the signals from Saturn (diameter ≈ 16″) to correct for the partial resolution of the planetary disk by using beam scans measured on Mars (diameter ≈ 7″). Saturn brightness temperatures were derived from the observed signals by the procedures outlined by Loewenstein *et al.* (3). The results are shown in Table 1.

An increase in temperature with wavelength in the submillimeter region is a feature common to all planetary atmosphere models for Saturn. Our 400-μm brightness temperature is in good agreement with profile C derived by Gautier *et al.* (4); however, the model predicts a 700-μm temperature greater than 150 K. Their model N, which gives a better fit to mid-infrared limb scans (5), predicts substantially higher temperature at both wavelengths. The Gautier *et al.* models are derived from observations in the far-infrared (20 to 200 μm), where the dominant opacity is due to pressure-broadened H_2 lines. In the submillimeter region there may be additional sources of opacity that would lower the brightness temperatures predicted by the models. Klein *et al.* (6) calculated models including opacity due to NH_3, which appear to give lower submillimeter temperatures; unfortunately, these models have been calculated only for λ > 1 mm. Clouds of NH_3 ice crystals (7) may also be an important source of opacity at submillimeter wavelengths. Our results seem to require an opacity source besides the pressure-broadened H_2 lines; models specifically related to the submillimeter region are needed.

The measurements reported here can be combined with earlier observations at larger ring inclination angles (≳ 20°) to estimate the submillimeter brightness of the rings. The presence of the rings affects the total submillimeter flux in two ways, through thermal emission from the rings themselves and through attenuation of the disk radiation where the rings overlap the disk. To calculate the emission from the rings, we assume that the A and B rings are equally bright and that they radiate as a Lambertian surface with a brightness temperature $T_R(\lambda)$. We calculate the attenuation of the disk radiation by assuming a wavelength-inde-

Table 1. Summary of Saturn observations.

Mean wavelength (μm)	Date (U.T. 1979)	Flux density ratio* (Saturn/Mars)	Surface brightness ratio† (Saturn/Mars)	Brightness temperature‡ (K)
400	27 November	2.56 ± 0.08	0.535	121
	28 November	2.56 ± 0.08	0.540	122
	Mean			121 ± 12
700	27 November	3.03 ± 0.09	0.633	137
	28 November	3.09 ± 0.09	0.652	141
	Mean			139 ± 15

*The observed signal ratio has been increased by 2 percent at 400 μm and 4 percent at 700 μm to correct for partial resolution of Saturn's disk. †Both planets are assumed to be uniformly bright. ‡The errors in brightness temperature are dominated by the 10 percent uncertainty in the assumed martian temperature (211 K). Other sources of error are the uncertainty in the resolution correction (2 percent), statistical uncertainties (≲ 1 percent), and the differences between the two nights (< 3 percent).

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pendent optical depth of 0.7 normal to the rings (*7-9*). For the size of the disk and rings we adopt the values given by Cook *et al.* (*9*).

Loewenstein *et al.* (*3*) observed Saturn with a passband similar to that of our 400-μm measurement in November 1975 and January 1976, when the ring inclination angle was 20° to 21°. Comparing our new results with the results of those observations, we find T_R (400 μm) = 72 ± 12 K. A similar comparison with the observations of Hudson *et al.* (*10*) in February 1974 (ring inclination angle, ≈ 27°) gives T_R (400 μm) = 92 ± 20 K. In both cases our error estimates are dominated by the uncertainty in the applicability of the martian model used for calibration. An attempt to resolve the rings at 400 μm (inclination angle, ~ 20°) with the 200-inch Hale telescope (*11*) yielded a lower value. Those observations imply an upper limit to the ratio of ring brightness to disk brightness of 0.35. Using our disk brightness temperature, we find that this would require T_R (400 μm) ≤ 52 K. The discrepancy between the results obtained by the two methods may be due to a difference between the A and B rings. Comparisons of total flux at different inclination angles give an average brightness for the rings; the scans made with the Hale telescope should be much more sensitive to the (outer) A ring than to the (inner) B ring.

The 400-μm ring brightness temperature lies between the brightness temperature (~ 90 K) observed for $\lambda \leq 35$ μm (*12*) and the temperatures (≤ 18 K) found for $\lambda \geq 3.3$ mm (*13*). This behavior, combined with the high optical depth of the rings at centimeter wavelengths (*8*, *14*), places severe constraints on the size and composition of the ring particles. The most likely candidates are metallic particles or ice particles with sizes of a few centimeters (*15*), although metallic particles seem less likely on the grounds of cosmic abundance and high density (*8*, *13*). Improved submillimeter observations should help to distinguish between the two compositions and to determine the size distribution.

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Responses of Hawaiian Plants to Volcanic Sulfur Dioxide: Stomatal Behavior and Foliar Injury

Abstract. *Hawaiian plants exposed to volcanic sulfur dioxide showed interspecific differences in leaf injury that are related to sulfur dioxide-induced changes in stomatal condutance. Species with leaves that did not close stomata developed either chlorosis or necrosis, whereas leaves of* Metrosideros collina *closed stomata and showed no visual symptoms of sulfur dioxide stress.*

In November 1979, Pauahi Crater, a Hawaiian volcano, erupted (*1*) and provided an opportunity to observe the effects of volcanic fumes on an adjacent forest stand. During the eruption, we observed that *Metrosideros collina* var. *macrophylla* Rock and *Dodonaea eriocarpa* Sm., which are evergreen woody species found throughout the Hawaiian Islands (*2*), appeared to differ greatly in their susceptibility to SO_2, the primary noxious gas in a volcanic plume (*3*). It has long been known that SO_2, an air pollutant in industrialized regions, injures foliage. Unfortunately, investigation of the processes that govern leaf uptake of noxious gases and result in foliar injury has begun only recently. We show here that species differ in stomatal responses to SO_2 and that changes in stomatal conductance during periods of SO_2 exposure are apparently associated with regulating the extent to which foliar injury develops.

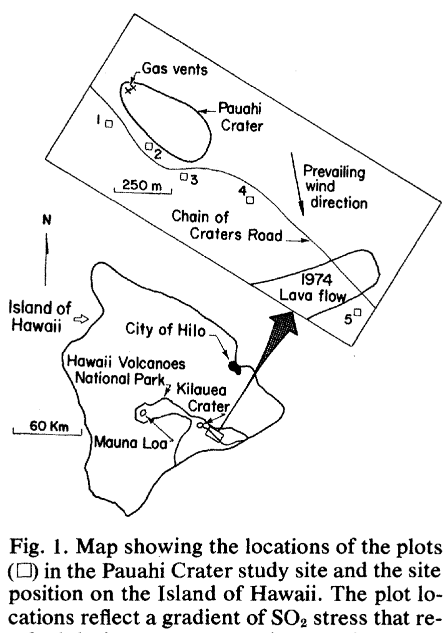

Fig. 1. Map showing the locations of the plots (□) in the Pauahi Crater study site and the site position on the Island of Hawaii. The plot locations reflect a gradient of SO_2 stress that resulted during a crater eruption on 16 November 1979. The crater is parasitic on Kilauea Caldera. Although ground fissures at the north end of the crater occasionally released magma and SO_2, most SO_2 in the study area originated from vents near the floor of the crater. The wind direction was constant in the study area during the eruption.

Long-term exposures to SO_2 at concentrations less than 0.5 parts per million (ppm) can alter the composition of plant communities (*4*), decrease the productivity of agricultural systems (*5*), and cause visible foliar injury (*6*). The nature of these large-scale effects and impairments is related to the effects of SO_2 on plant metabolism. Recent studies show that SO_2 concentrations between 0.1 and 1.0 ppm can cause rapid changes in stomatal conductance for a wide range of plant species, including evergreen shrubs, deciduous shrubs, and herbaceous species (*7, 8*). Changes in stomatal conductance caused by SO_2 alter the flux rate of

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