OBSERVATIONS OF VENUS, MARS, JUPITER AND SATURN LONGWARD OF 2000 Å

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ABSTRACT

A number of high quality spectra of Mars, Jupiter, the combined disk and rings of Saturn, as well as lower quality spectra of Venus, have been obtained with an objective grating spectrometer of the Wisconsin Experiment Package of OAO-2. An intercomparison of the Mars, Jupiter and Saturn spectra has failed to disclose any discrete planetary absorptions. Continuous albedos have been derived for the four planets by using OAO-2 observations of G-type stars for $\lambda > 2700$ Å and a new photoelectric solar spectrum by A. L. Broadfoot for $\lambda < 2700$ Å. The geometric albedo of Mars shows a steady increase below 3500 Å which appears to be due to Rayleigh scattering combined with a decreasing surface reflectivity. The albedos of Venus, Jupiter and Saturn show a maximum in reflectivity in the region of 2500 Å.

I. INTRODUCTION

The second Orbiting Astronomical Observatory (OAO-2) was launched in December 1968. At the time of writing (~2-1/2 years later) the Wisconsin Experiment Package in OAO-2 is still successfully obtaining high quality ultraviolet astronomical data. The observatory has been used for making ultraviolet observations of stars, gaseous nebulae, interstellar matter, star clusters, galaxies, diffuse background radiation, and solar system objects such as comets, planets and the zodiacal light. Thus far the planets Venus, Mars, Jupiter, Saturn, Uranus and Neptune have been observed with either broadband photometers or low-resolution spectral scanners. In this paper we present the results of observations of Venus, Mars, Jupiter and Saturn longward of about 2000 Å.

The Wisconsin Experiment Package has been described by Code <u>et al</u>. (1970). The package contains four 8-inch broadband ultraviolet photometers, one 16-inch broadband photometer, which failed before planetary observations were made, and two objective grating scanning spectrometers. One spectrometer operates between 1050 Å and 2000 Å with a nominal resolution of 10 Å. The other spectrometer operates between 1800 Å and 3600 Å with a nominal resolution of 20 Å. This paper considers the scanner and photometry data on the brighter planets longward of 2000 Å. These data have been used to derive geometric albedos over the spectral region 2100-3600 Å. Observations at shorter wavelengths with the scanners have not revealed measurable planetary fluxes.

In § II we discuss some aspects of the data reduction and in § III we discuss the method of determining the continuous albedos. In § IV we present the results of an unsuccessful search for absorption features which are narrow enough to be undetected in the continuous albedos obtained in § III. In § V we compare the OAO data with previous observations and in § VI we discuss the results.

II. DATA REDUCTION

The longer wavelength spectrometer scans between 1800 Å and 3600 Å in discrete steps of approximately 20 Å. The exit slit width is 20 Å and the integration time used for the planetary observations was 8 seconds per step position except for a single scan of Saturn with a 64-second integration time. With the 8-second integration time the spectrum from 1800 Å to 3600 Å was scanned in about 13 minutes. Typically a planet was scanned twice in one night period of the satellite's orbit.

Table 1 lists the various scans that were analyzed in this paper along with data concerning the planets at the time of observation. Other scanner observations were attempted but those data were judged to be of poor quality because of various observing problems. The data on Venus listed in Table 1 are of lower quality than those on Mars, Jupiter and Saturn. When the Venus observations were attempted the digital counter was inoperative, so that only an analog signal of lower quality was recorded. Restrictions on the pointing of OAO-2 close to the sun prevented us from obtaining additional Venus data.

Repeated observations of objects with the long wavelength spectrum scanner have shown that the count rate at any given

Table 1. OAO Spectral Scans Used in the Analysis

Planet	Orbit & Data Frame Number of Scan	Date (1969)	Hour (U.T.)	Phase Angle (Degrees)	Comments
Venus	1029(1) 1029(3)	February 16	21 h	103.0	
Mars	1608(2) 1608(4) 1610(1) 1610(2)	March 29	5 h	34.5	Longitude of Central Meridian (LCM) = 120°
	1966(12)	April 23	1 h	26.8	LCM = 200°
Jupiter	2316(23) 2317(3) 2317(4)	May 17	12 h	9.3	LCM (System II) = 123°
	2510(2) 2510(3)	May 31	17 h	10.3	LCM (System II) = 64°
Saturn	2782(23) 3124(1)	June 19	20 h	6.2	Ring Parameters B=17.8 B'=15.9
	3125(5)	July 12	17 h	6.0	B=18.4 B'=16.2

wavelength varies by about ±30% over periods of several days. This problem is due to difficulties in the discriminator circuit of the scanner. The observed spectral distributions are, however, highly reproducible (±2 to 4%) (Bless and Savage 1972). Because of the discriminator problem, planetary albedo curves have been determined by using the scanner data to set the relative run of the albedo while OAO broadband photometry data and ground-based photometry data were used to set the absolute level of the albedo.

A. D. Code (private communication) has provided the spectrometer calibration curve which allows the counts to be converted into relative flux units. This curve has been derived from a combination of (1) a laboratory calibration performed one year before the flight; (2) OAO observations of early-type stars compared to models; (3) OAO observations of α CMa compared to Stecher's (1970) calibrated photometric measurements of this star. Calibration curves based on all the above methods agree to within 15% over the region 1800-3600 Å. We believe that the spectrometer relative calibration curve used here is accurate to ±10%.

Figure 1 gives a typical scan of Mars on a linear signal scale. It is apparent that below 1900 Å, where the solar flux is falling off rapidly, the signal remains constant. For the planets fainter than Jupiter this signal is at approximately the dark level but shows some variation which is due to the influence of the Earth's radiation belts and background light accepted by the objective grating instrument. A larger short-wavelength signal from Jupiter (which was about five times brighter than Mars) is due to scattering of the Jupiter light internal to the instrument. From scans of the sky with the long wavelength spectrometer it was found that the sky background typically increases from about 5 counts to 9 counts when scanning from 1800 Å to 3600 Å (one OAO count corresponds to 64 photoevents). Thus to correct the OAO scans of the planets fainter than Jupiter, we have assumed that the background is sky background and made a correction in which the observed level at 1800 Å increased linearly by 4 counts to 3600 Å. In the case of the Jupiter scans, we have assumed the scattered light contribution to the background to be the same at longer wavelengths as it was at 1800 Å. In all cases the uncertainty introduced by the background correction is small longward of 2300 Å because of the large increase of the planetary signal. In § III we will discuss the possible uncertainties introduced into the measurements by these background corrections.

Because the spectrometer has no entrance slit the wavelengths of the data points are subject to uncertainties due to pointing errors in the attitude control system and to errors in the predicted target position. Consequently, it was neces-

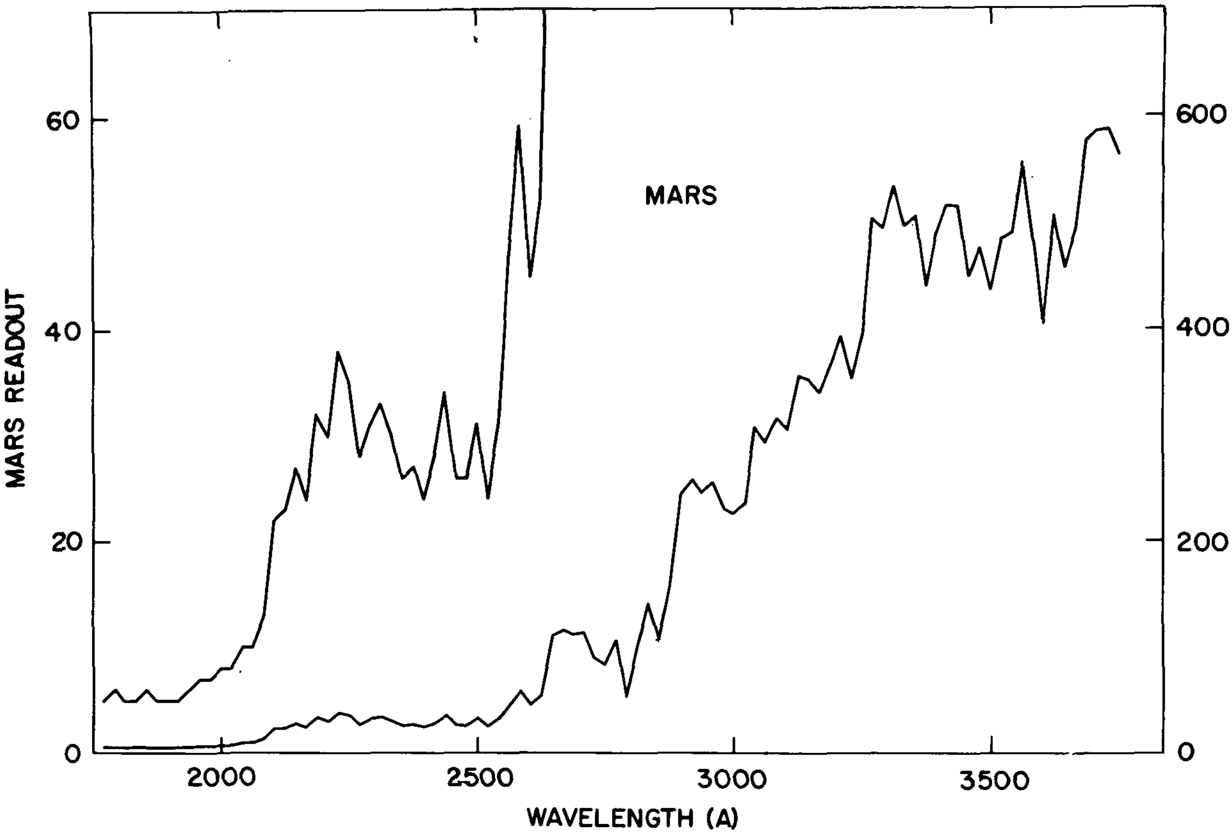

Figure 1.—OAO-2 spectral scan of Mars. The data points, connected with straight line segments, are given on two scales differing by a factor of 10. The telemetered readout is the photo event count divided by 64.

sary to establish the wavelength scale for each spectrum by comparison with a synthetic solar spectrum. We generated this synthetic spectrum from the digitized version of the NRL solar material given by Brinkmann, Green and Barth (1966) for wavelengths less than 2990 Å, and the digitized version mainly of Brückner's (1960) material given by Furukawa, Haagenson and Scharberg (1967) for wavelengths greater than 2990 Å, smeared to the resolution of the instrument. The wavelength determinations appeared accurate to the order of 1 Å in the region of 2800 Å and perhaps as uncertain as 3 Å at other wavelengths.

III. CONTINUOUS ALBEDOS

Preliminary OAO albedo curves were discussed by Wallace (1970) and Caldwell (1971). Solar data used to obtain those curves were taken from Brinkmann et al. (1966) for wavelengths less than 2990 Å and from Furukawa et al. (1967) for longer wavelengths. When the OAO albedos were joined to ground-based albedos at 3600 Å, all the curves showed an abrupt change in slope at 3600 Å. Since it was physically unreasonable to expect all planets to exhibit this unusual feature, it was concluded that these preliminary curves were in error because of uncertainties in the solar ultraviolet data.

As a result of these problems, we have developed a reduction method that avoids using the ultraviolet solar data cited above. Two fortunate circumstances have made possible a significant improvement over the preliminary curves. First, Broadfoot (1972) has made available to us before publication his recent photoelectric measurements of the sun in the ultraviolet. Second, Caldwell (1971) has demonstrated that OAO observations of late-type stars similar to the sun can be used to obtain accurate planetary albedos down to a wavelength of about 2700 Å. This second procedure has the advantage that albedos can be derived which are independent of the sensitivity curve of the scanner and a solar spectrum measured by another instrument. Caldwell (1971) found that, for unreddened late-type stars of luminosity classes V and IV, their (B-V) colors are excellent indicators of the stars' ultraviolet energy distributions. For a detailed discussion of OAO late-type star photometry see Doherty (1972). To take advantage of this correlation of flux distribution with color, it is necessary to know $(B-V)_\odot$. However, it is extremely difficult to measure this parameter precisely. $(B-V)_\odot$ has been determined through several indirect means to be 0.65 ± 0.01 by van den Bergh (1965). More recent determinations by Fernie et al. (1971) of 0.628 ± 0.011, by Alexander and Stansfield (1966) of 0.663 ± 0.008, and by Spite (1966) of 0.68 bracket the result of van den Bergh. For this paper, we used the value 0.65. This is also the value of $(B-V)_\odot$ generally used for interpolating among standard star observations to obtain albedos in the visible region of the spectrum (Young and Irvine 1967; Irvine et al. 1968a,b). An uncertainty of ±0.02 in $(B-V)_\odot$ will introduce an uncertainty into albedo determinations of ±10% at 3600 Å, ±20% at 2600 Å, and ±30% at 2200 Å. Because of this increasing uncertainty toward shorter wavelengths and because OAO scanner observation of G stars are generally unreliable below 2500 Å, we proceeded to generate albedo curves as follows: (1) We used OAO scanner data for the G star ζ Her (B-V = 0.65) to obtain relative albedo curves down to 2700 Å. Interpolation among G stars having (B-V) colors from 0.55 to 0.75 to a (B-V) of 0.65 produced a spectrum essentially identical to that of ζ Her for $\lambda > 2500$ Å, so that it is expected that the relative shapes of the albedo curves in this region are very accurate. (2) At wavelengths less than 2700 Å, we used Broadfoot's (1972) photoelectric solar spectrum. (3) The long and short wavelength sections of the albedo curves were joined in the region 2650-2700 Å. (4) The absolute level of the OAO albedo curves was determined by OAO broadband filter photometry in those cases where it was available; otherwise the data were scaled to the ground-based photometry of Irvine's group. This procedure was made necessary by the previously mentioned sensitivity changes of the scanner. Since each broadband OAO photometer has a Cerenkov calibration source, absolute sensitivity changes of the OAO photometers (which proved to be small) could be accounted for. The OAO broadband filters used for this purpose have effective wavelengths (for G2 stars) and full widths at half intensity of 3075 Å (FW = 420 Å) and 3062 Å (FW = 440 Å).

To calculate geometric albedos from OAO broadband filter data, photometry of ζ Her was used. The photometric data for this star are: V = 2.81, (B-V) = 0.65, (U-B) = 0.21 (Johnson et al. 1966). For the sun, we used: $V_\odot = -26.74$ (Johnson 1965), $(B-V)_\odot = 0.65$ (van den Bergh 1965), $(U-B)_\odot = 0.14$ (Fernie et al. 1971). All ζ Her photometry was scaled to the sun by adjustment of the U magnitude (ΔU = 29.62). Planetary radii were taken from Dollfus (1970) and planetary distances were taken from The American Ephemeris and Nautical Almanac. Good OAO broadband photometry, taken within a few hours of the respective scans, exists for Mars (at phase angle 26.8°), for Jupiter and for Saturn. For the other OAO scanner data it was necessary to normalize the OAO observations to ground-based photometry because in these cases the OAO photometry observations were not successful.

The OAO geometric albedos for Venus, Mars (at two phase angles), and Jupiter are plotted in Figures 2, 3, 4 and 5. These geometric albedos are defined as the ratio of the observed brightness to the brightness of a Lambert disk at the same distances and of the same size as the planet, but observed at zero phase angle. For Saturn (disk plus rings) we give, in Figure 6, the ratio of the measured brightness compared to that of the sun. In these figures we also give the corresponding ground-based measurements. The curves were evaluated for 100 Å averages of the ratio planet/ζ Her for λ > 2700 Å, and the ratio planet/sun for λ < 2700 Å. The two Venus scans (see Table 1) were combined and represent the planet at a phase angle of 103°. The curves for Mars for the two phase angles are presented separately because the change in phase angle was large. The four scans at the phase angle of 34.5° were combined. Since the five independent Jupiter scans all exhibited the same spectral variation, they were combined to represent the planet at a phase angle of 10°. Similarly, the three Saturn scans were combined to represent the planet at a phase angle of 6° and ring inclinations of B = 18° and B' =

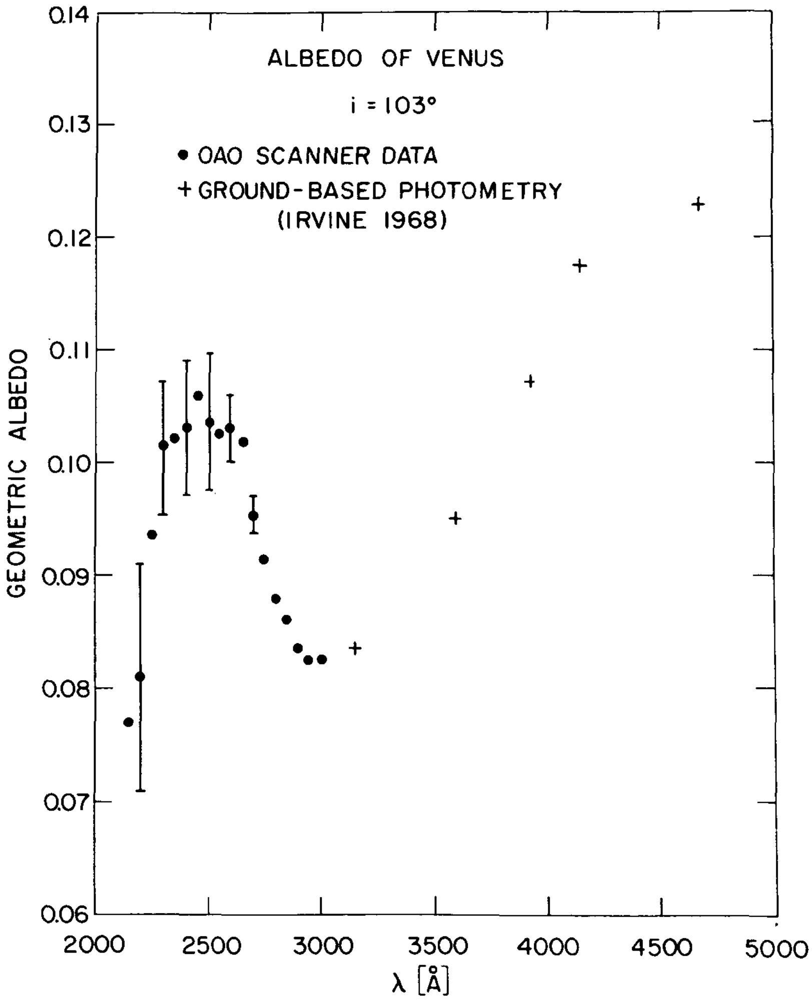

Figure 2.—Continuous geometric albedo of Venus at a phase angle of 103°. The error bars indicate the possible error due only to the uncertainty in the background correction. The absolute level of the OAO curve has been adjusted to smoothly join onto the ground-based data of Irvine (1968).

16°. As was the case for Jupiter, there was no indication of any change in spectral detail, so that no information was lost by combining scans.

The ground-based photometric data plotted in Figures 2, 3, 4, 5 and 6 were taken from the results of various papers reporting on the data of the Harvard College Observatory planetary photometry program. For Venus, albedos for the phase angle of 103° were obtained from the data of Table I of Irvine (1968). The data of Irvine et al. (1971) were used to calcu-

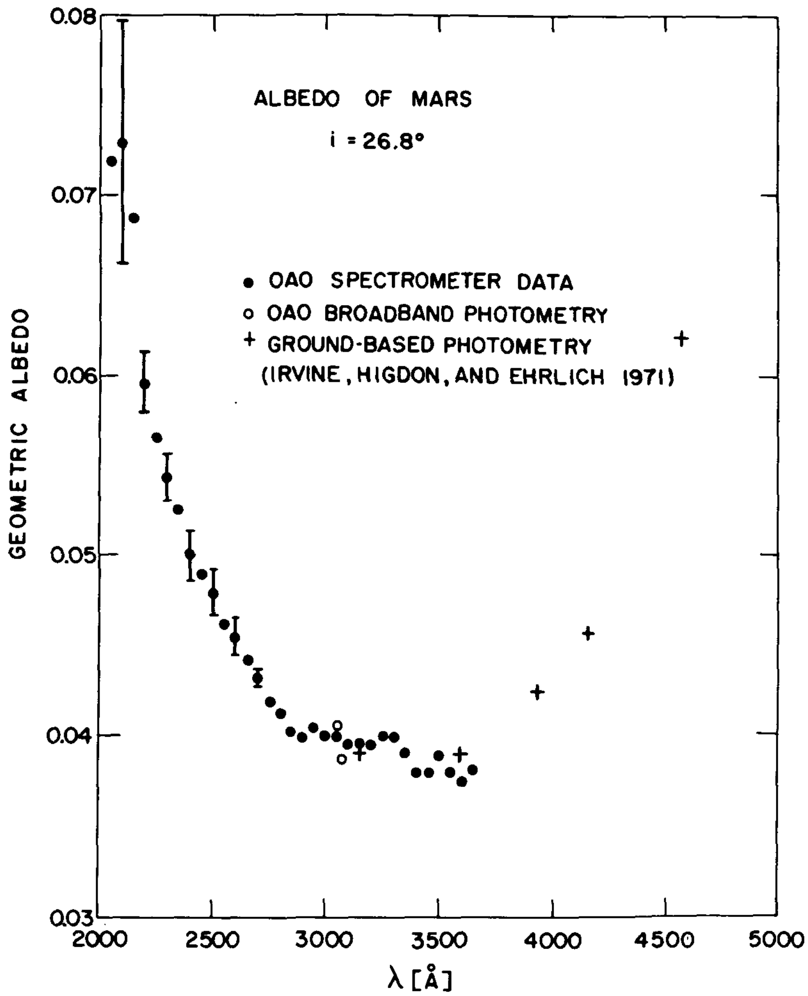

Figure 3.—Continuous geometric albedo of Mars at a phase angle of 26.8°. The error bars indicate the possible error due only to the background correction. The absolute level of the OAO curve has been set by the OAO broadband photometry. The ground-based data from Irvine, Higdon and Ehrlich (1971) are for the phase angle of the OAO observation.

late geometric albedos for Mars for phase angles of 34.5° and 26.8°. The magnitudes and phase coefficients derived by Irvine et al. (1971) using data only from phase angles greater than 15° were used here, that is, columns two and three of their Table I. These authors made this restriction because their observations at smaller phase angles are affected by the zero-phase anomalous brightening. Since the zero-phase effect is not important for the OAO observations, the comparable ground-

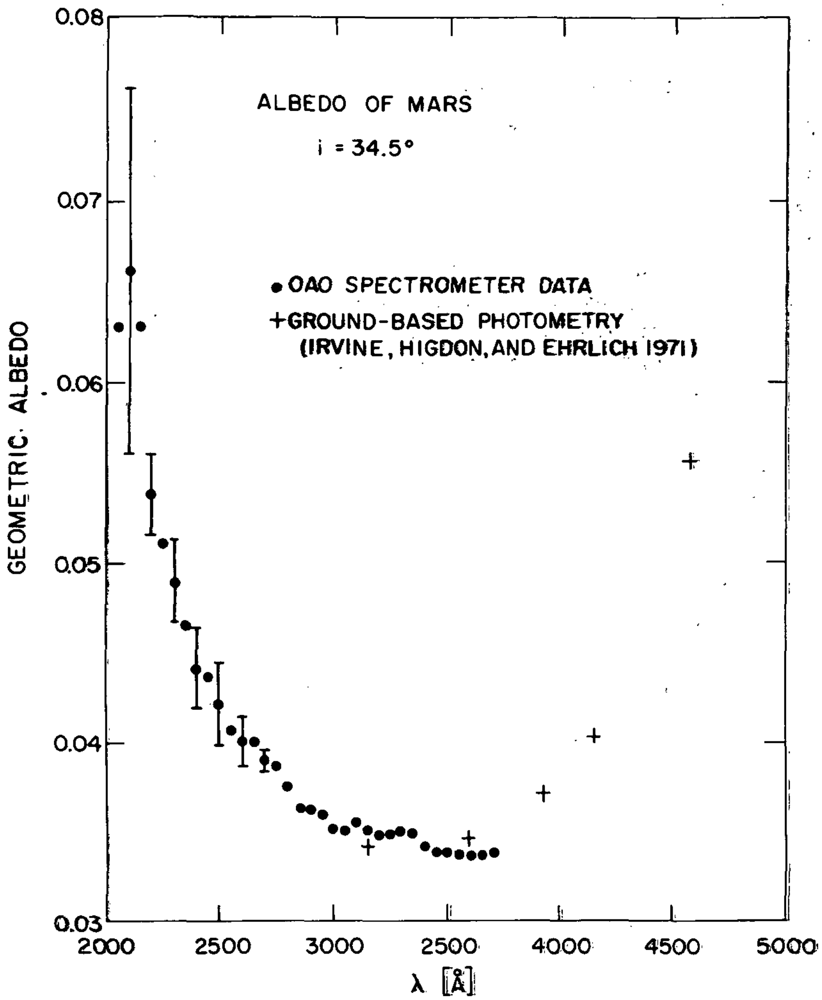

Figure 4.—Continuous geometric albedo of Mars at a phase angle of 34.5°. The error bars indicate the possible error due only to the background correction. The absolute level of the OAO curve has been adjusted to the ground-based data of Irvine, Higdon and Ehrlich (1971) for the phase angle of the OAO observation.

based data excluding it were used here. For Jupiter, Hopkins and Irvine (1971) present albedo calculations for three different apparitions (their Table II). For the present paper, these results were averaged, and a phase coefficient of 0.005 magnitudes per degree (Irvine et al. 1968b) was used to derive geometric albedos at a phase angle of 10°. For Saturn, the data of Irvine and Lane (1971) were used. Average phase coefficients were computed from their Table I for each of their fil-

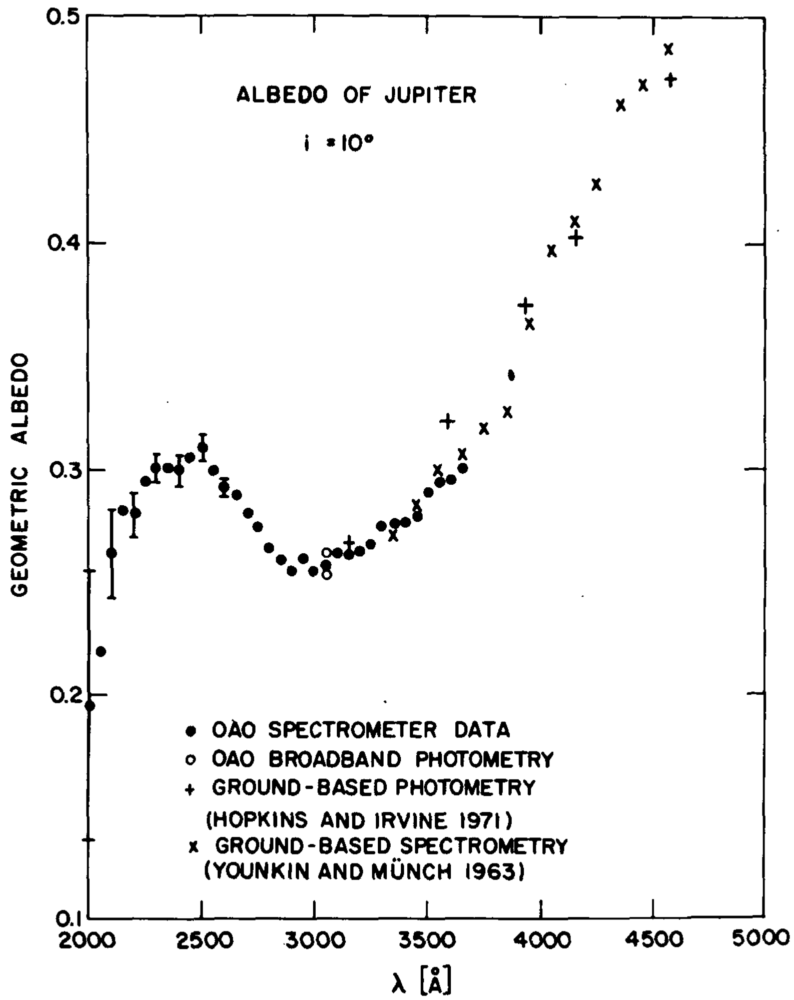

Figure 5.—Continuous albedo of Jupiter at a phase angle of 10°. The error bars indicate the possible error due only to the background correction. The absolute level of the OAO curve has been set by the OAO broadband photometry data at 3062 Å. The ground-based data of Hopkins and Irvine (1971) for a phase angle of 10°, as well as the relative ground-based data of Younkin and Münch (1963) adjusted to the data of Hopkins and Irvine, are also shown.

ters, and these were used with their values of m_{nr}, a and a' (presented in their Table III) to calculate total brightness (rings and planet) for the phase angle of 6° and ring inclinations B = 18° and B' = 16° at which Saturn was observed by the OAO. For Saturn (see Figure 6) we have also indicated the contributions from the planet alone as calculated from the data

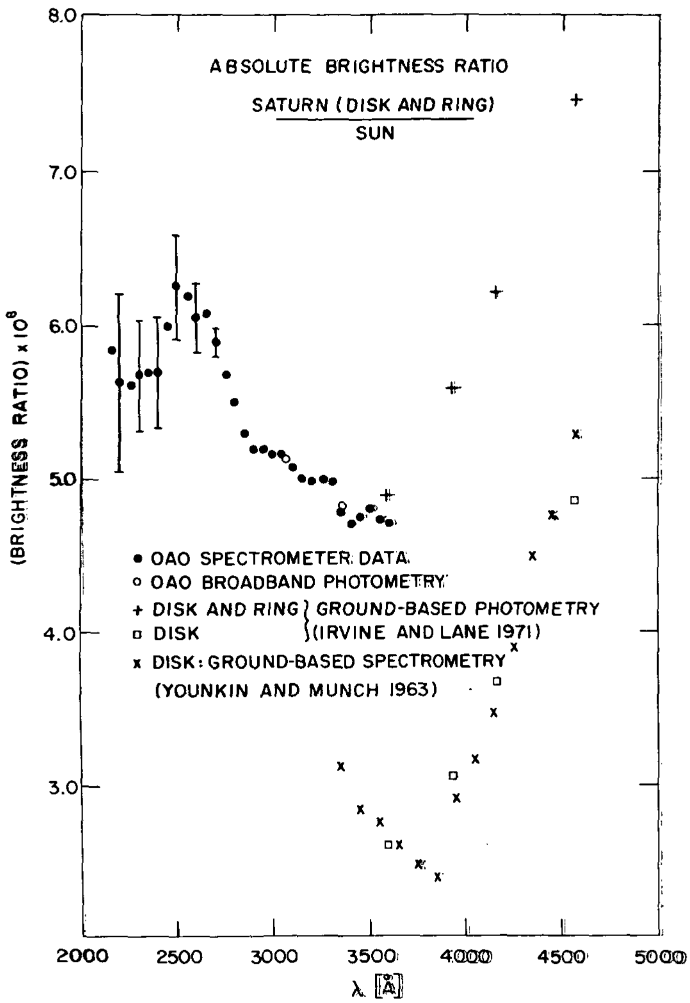

Figure 6.—Absolute brightness ratio of Saturn (disk plus ring). The phase angle was 6° and the ring inclinations B = 18° and B' = 16°. The error bars indicate the possible error due only to the background correction. The absolute level of the OAO curve has been set by the OAO broadband photometry data at 3062 Å and 3590 Å. The ground-based data of Irvine and Lane (1971) for the disk and rings together and disk alone are shown for the phase and inclinations of the OAO data. The relative ground-based data of Younkin and Münch (1963) adjusted to the data of Irvine and Lane are also shown.

of Irvine and Lane (1971). Since the rings contribute a major part of the observed light from the planet, and since we have no data on the variation of brightness with ring inclination in the ultraviolet, the Saturn curve is represented as an absolute ratio of planet (disk plus rings) to solar brightness, rather than as a geometric albedo. For all planets, calculated ground-based albedos were adjusted for the values of $V_{\odot}$ (-26.74) and planetary radii (Dollfus 1970) used here, which are slightly different than those used by Irvine and his group.

The error bars in the geometric albedo curves show the uncertainty due to possible errors in the background correction. These errors depend on the quality of the data and were judged to range from 20% of the background correction in the best cases to 40% in the worst cases. Over the region 2100-2700 Å, further sources of possible error are: (1) OAO calibration curve errors and (2) errors in Broadfoot's (1972) photoelectric solar spectrum. The combined effects of these two sources of error lead to an uncertainty that is unlikely to exceed 15%. Over the region 2100-2700 Å Broadfoot's (1972) solar spectrum used here was very similar (±10%) to the NRL spectrum except for the region 2400-2700 Å where the difference became as large as 20%. In the region 2700-3600 Å, the uncertainty of $0^{m}.02$ $(B-V)_{\odot}$ introduces an uncertainty of about 10% in the albedo determinations. In summary, over the region 2100-3600 Å, the relative accuracy of these albedo curves is probably about ±10 to 15%.

As can be seen from Figure 2, the absolute normalization of the OAO observations of Venus is less certain than for the other planets because there is no planetary broadband OAO photometry, and the scanner data do not overlap with the ground-based observations. The absolute level of the albedo shortward of 3000 Å depends on the assumption that there are no spectral features in the gap from 3000 Å to 3150 Å. Longer wavelength scanner data were lost because the signal recorded for Venus was saturated.

IV. NARROW ABSORPTION FEATURES

We have made a detailed intercomparison of the planetary spectra in order to detect narrow absorption features which would have gone unnoticed in the continuous albedos derived in § III. Small photometric errors and uncertainties in the instrumental profiles make the use of the solar spectrum for this purpose very unprofitable (cf. Anderson et al. 1969). The chance coincidence of a trace absorber common to the two planets being compared would, of course, lead to a negative result. However, the physical natures of the planets under consideration are different enough that such coincidences are unlikely.

Since the continuous albedos of the planets are significantly different, only short strips of spectra of the different planets 50 Å to 100 Å long, could be compared at a time. This comparison showed no differences significant to within the scatter of the data. We have also constructed Jupiter/Mars ratios at 100 Å intervals using 100 Å strips of the data and used these ratios to scale the Mars spectra to Jupiter. The result of this process is given in Figure 7. Again there do not appear to be any significant differences.

The peak-to-peak scatter in the data of Figure 7 is given in Figure 8. The general increase in scatter from long wavelengths to short is due to the decreasing signal. In addition, an increase in the scatter is apparent where the signal level changes rapidly. Below about 2175 Å the signal-to-noise ratio decreases rapidly so that the data contain essentially no information on narrow features. Figure 9 gives the result scaling the Saturn spectra to Mars, again showing no significant features. The corresponding peak-to-peak scatter is about 1.2 times greater than that given in Figure 7. The Venus spectra were not good enough to warrant a similar comparison.

The scanner obtained only one data sample per 20 Å slit width instead of the three or more per slit width usually obtained with such instruments. In addition, the data points for the Jupiter spectra occur in 4 Å wide clusters separated by about 16 Å gaps; those for Mars occur in 10 Å wide clusters centered in Jupiter gaps. This character is apparent in Figures 7 and 9 and is presented in more detail in Figure 10. The mean wavelengths of the Jupiter sampling points are given in Table 2.

To investigate how much narrow absorption could be hidden between two successive data points we have constructed a series of synthetic profiles. The instrumental profile was taken as the convolute of a square wave 20 Å wide, representing the exit slit, and a uniform disk 6 Å wide, representing the disk of Jupiter. We then convolved this profile with a series of absorptions of Gaussian shape, zero residual intensity, and a range of half widths. Finally, these synthetic profiles were compared with a grid of sampling points separated by 21 Å to establish as a function of position between grid points and the peak-to-peak noise in the data, how large an absorption could be hidden. For a profile centered on an observed wavelength this was taken as the product of the percentage peak-to-peak noise and the 20 Å wide slit. The results are given in Figure 11. As the center of the profile is displaced from an observed wavelength the maximum equivalent width remains constant since the profile, for small absorptions, retains a flat bottom in the central region. Displacements beyond that point indicate that rapidly increasing amounts of absorption could be hidden, becoming a maximum when the profile is centered between two observed wavelengths. Other approximations, including a planetary disk of zero width and a square absorption

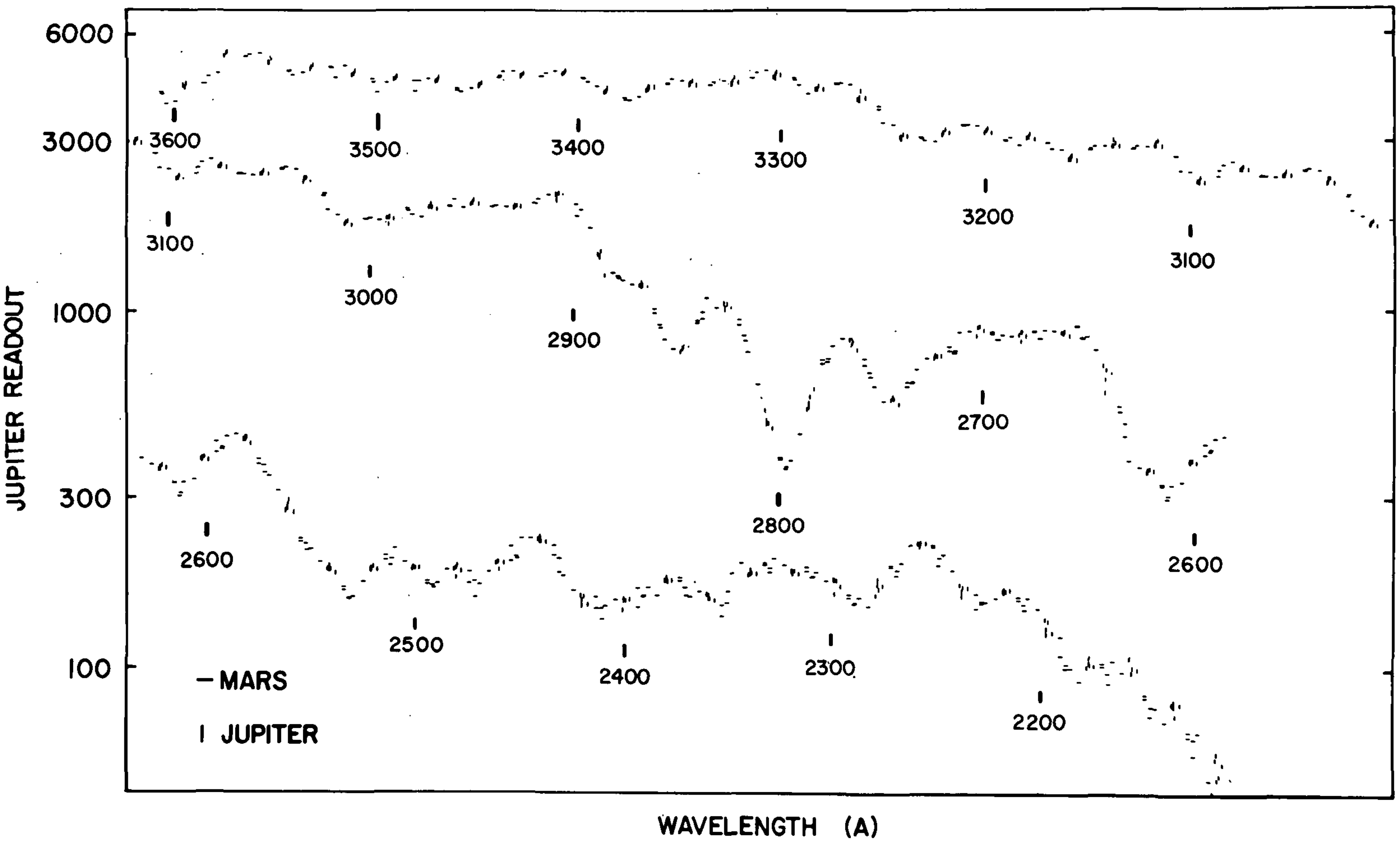

Figure 7.—A comparison of the Jupiter spectrum with adjusted spectrum of Mars. The adjustment, at 100 Å intervals, compensated for the difference in continuous albedos. The lack of significant residual differences between the two spectra indicates that there are no significant narrow absorption features in either spectrum.

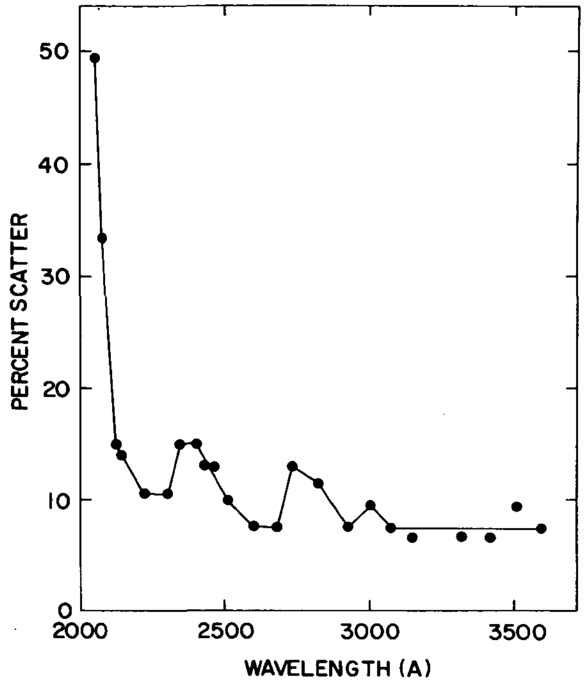

Figure 8.—Peak-to-peak scatter in units of the signal level of the combined Jupiter-Mars spectrum of Figure 7.

with zero residual intensity yield essentially identical results. Consequently, we believe the estimates given in Figure 11 are conservative. Since the results are very insensitive to the size of the planetary disk, as long as it is small compared to the slit width, they can be used equally well for Mars, Jupiter and Saturn.

The equivalent width of a potential feature can be estimated by obtaining the wavelength displacement from Figure 10 and Table 2, the peak-to-peak noise from Figure 8, and then the equivalent width from Figure 11.

V. COMPARISON WITH PREVIOUS OBSERVATIONS

The present results longward of about 2300 Å are superior to those previously reported. The spectra are inherently cleaner and we have been able to use an improved solar reference synthesized from observations of solar-type stars obtained with the same instrument for $\lambda > 2700$ Å, while for $\lambda < 2700$ Å we have made use of an improved photometric solar spectrum. The remarkable agreement between the OAO albedos and the independently derived ground-based albedos seen in Figures 3, 5 and 6 gives an indication of the quality of these new data.

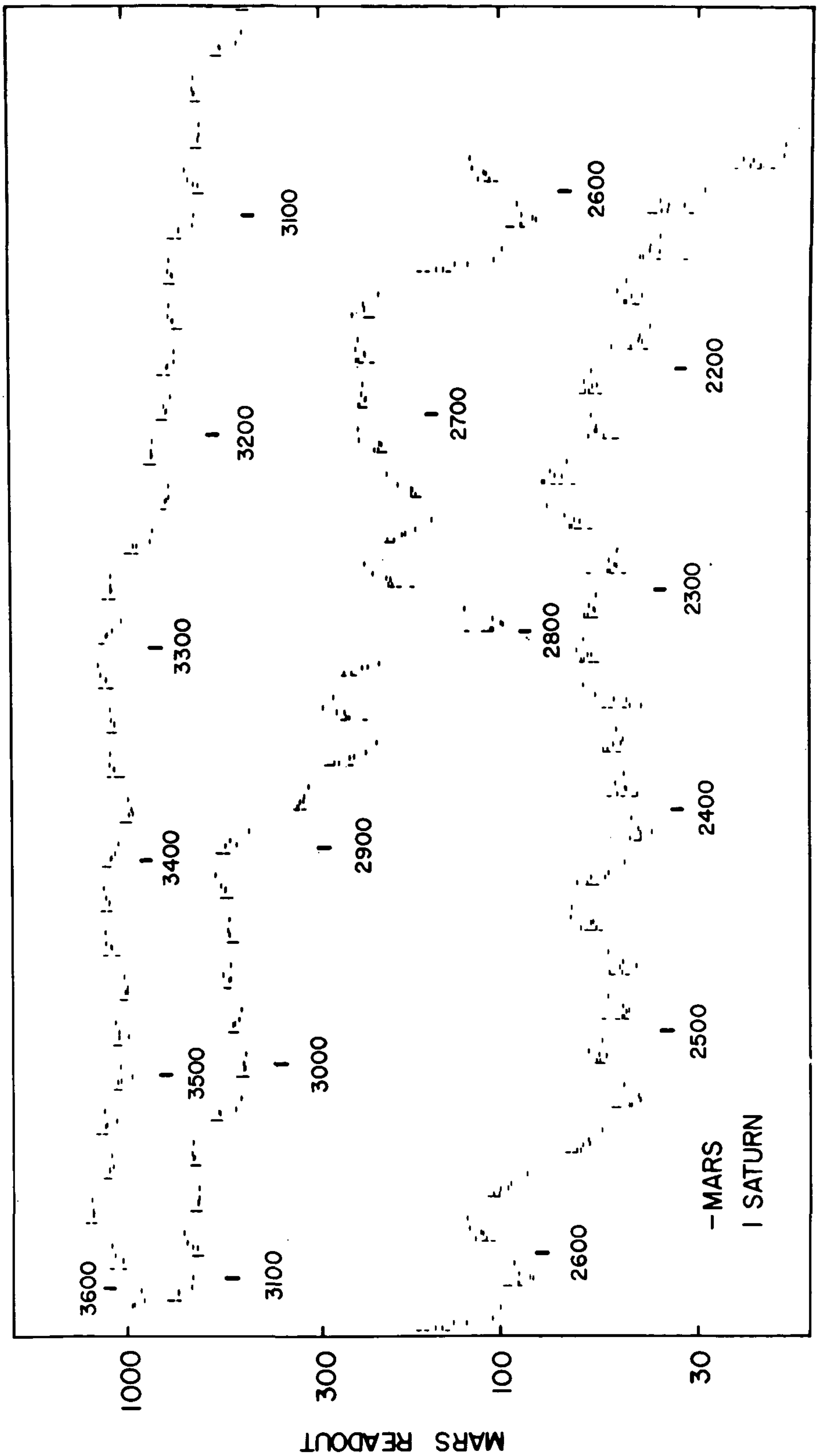

Figure 9.—*A comparison of the Mars spectrum with the adjusted spectrum of Saturn. See caption to Figure 7.*

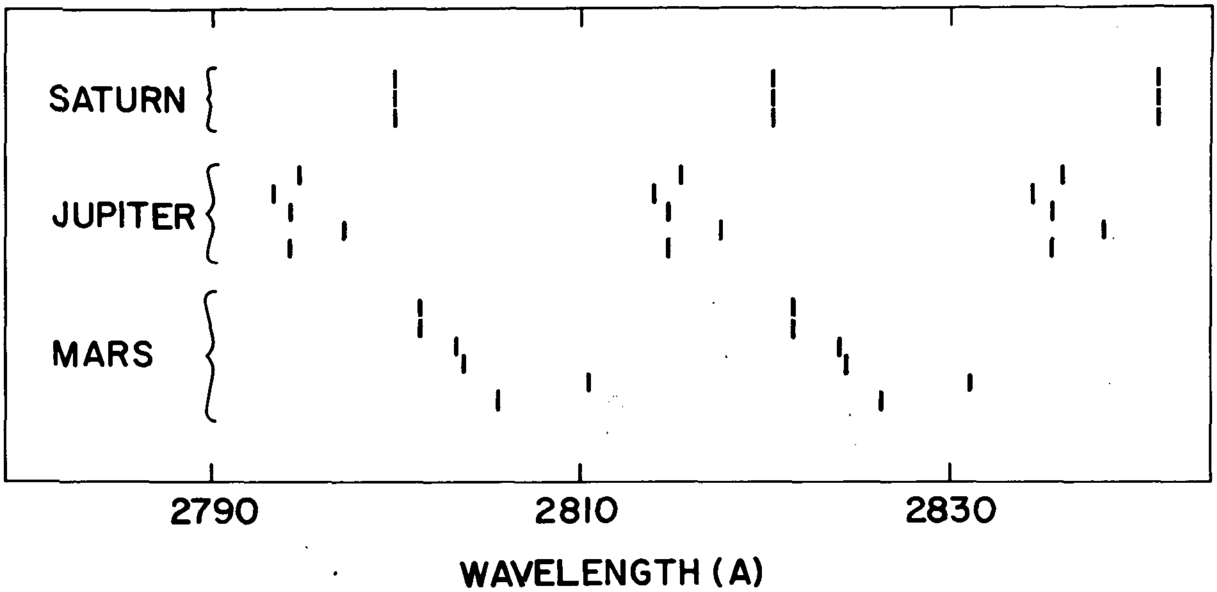

Figure 10.—Wavelengths sampled near 2820 Å in the spectra of Mars, Jupiter and Saturn.

The data of Anderson et al. (1969) for Venus do not show as pronounced a hump at ~2500 Å as our data but they do extend to shorter wavelengths and exhibit a cutoff due to CO_2 absorption beginning at about 2100 Å. The less well-defined data of Jenkins, Morton and Sweigart (1969) suggest a hump at ~2400 Å similar to what we have observed. The broad minimum in the albedo at ~2600 Å suggested by the results of Evans, Boggess and Scolnik (1965) and Evans (1967) has not been verified by the subsequent observations. Possible narrow absorptions at about 2174 Å suggested by Jenkins et al. (1969) and at 2145 Å suggested by Anderson et al. (1969) do not appear to be real.

Evans' (1965) determination of the Mars albedo disagrees only slightly with the OAO determination, since the OAO material is almost included within his error estimates (0.07 to 0.20 at 2400 Å). Broadfoot and Wallace (1970) reported a Mars albedo flat to within about 5% from 3200-2500 Å whereas our results show a 20% increase over the same region. The difference may be due to the different solar reference spectrum. Similarly the dip in the Mars albedo at 2500 Å reported by Wallace (1970) and Caldwell (1971) on the basis of the same planetary spectra used here, does not appear in the present reduction because of the different solar reference spectrum. Barth and Hord (1971) have reported ultraviolet spectra and albedos obtained with Mariners 6 and 7. Since they were ob-

Table 2. Mean Wavelengths of Jupiter Sampling Points

2094	2618	3113
	39	33
2115	60	54
35	81	74
56		94
77	2702	
98	23	3215
	43	35
2219	64	55
40	85	76
61		96
82	2805	
	26	3316
2303	46	37
24	67	57
45	88	78
66		98
87	2908	
	29	3418
2408	49	39
29	70	59
50	91	79
71		
92	3011	3500
	31	20
2513	52	40
34	72	61
55	92	81
76		
97		

tained at high spatial resolution they are not directly comparable to our results. We can only note that their curve for desert regions shows a factor of 2 increase in reflectivity going from 3500 to 2700 Å, at variance with both the present results and those of Broadfoot and Wallace (1970) obtained in integrated light. Of more importance is their ratio of polar cap spectra to desert spectra which show a broad minimum of about 30% depth entered at ~2500 Å which could be due to ozone absorption. Such a characteristic does not contradict our data because at the time of the OAO observations the projected areas of the north polar cap and southern hood were only 2% and 17% that of the disk.

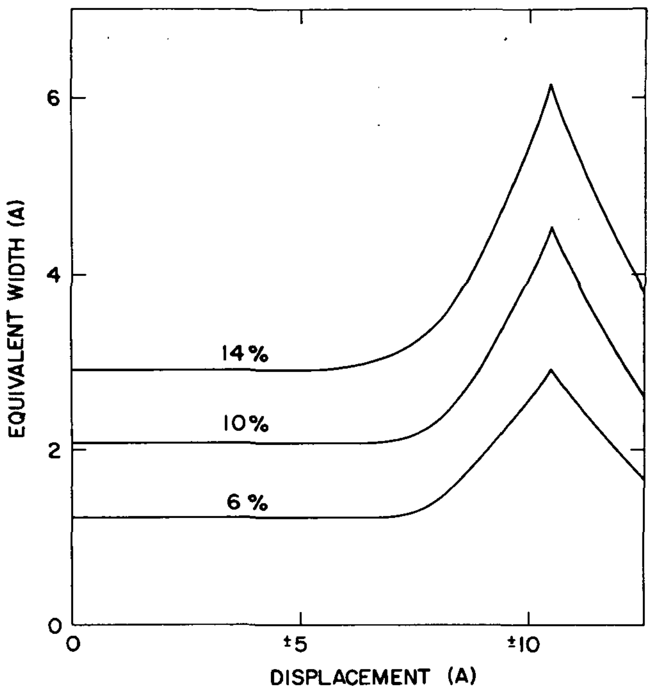

Figure 11.—Maximum equivalent widths of narrow features as a function of peak-to-peak scatter in the data and the difference between wavelength of the features and the wavelength of a point observed.

The Jupiter albedos given by Stecher (1965) and by Evans (1967) are very uncertain and, except for a broad absorption feature at 2600 Å, are consistent with the OAO albedo. Their feature at 2600 Å has not been confirmed by any of the subsequent observations. As with Venus, the Jupiter albedo given by Anderson et al. (1969) does not show as large a hump at 2500 Å as does the OAO data. Their data is better defined shortward of about 2200 Å. Kondo's (1971) Jupiter albedo from 2200-3600 Å differs from ours by no more than 5 or 10% in spite of his use of the Brinkmann-Furukawa version of the solar spectrum. The narrow absorption at 2165 Å mentioned by Anderson et al. (1969) does not appear to be real.

The measurements of Saturn (disk and rings) by Bless, Code and Taylor (1968) at 2450 Å, 2800 Å and 2950 Å are less certain than the OAO data but indicate the same trend.

VI. DISCUSSION

A detailed analysis of the albedos is not presented here since the results of such a process are highly model dependent.

This has been illustrated by Anderson et al. (1969) in their attempts to interpret the ultraviolet albedos of Venus and Jupiter. The general features are, however, worth discussion in view of the fact that any systematic errors that exist in our determinations of the continuum albedos are common to all four of the planets. As we noted earlier, these errors could amount to ~15% and would be more likely to occur shortward of 2700 Å since longward of 2700 Å the use of ζ Her as the solar reference makes the albedos independent of instrumental calibrations.

In order to intercompare the shapes of the albedos we have replotted them on a logarithmic scale in Figure 12. This shows fairly clearly that Venus, Jupiter and Saturn have humps of similar magnitude at ~2500 Å which do not appear in Mars. In previous reductions of these data using the Brinkmann version

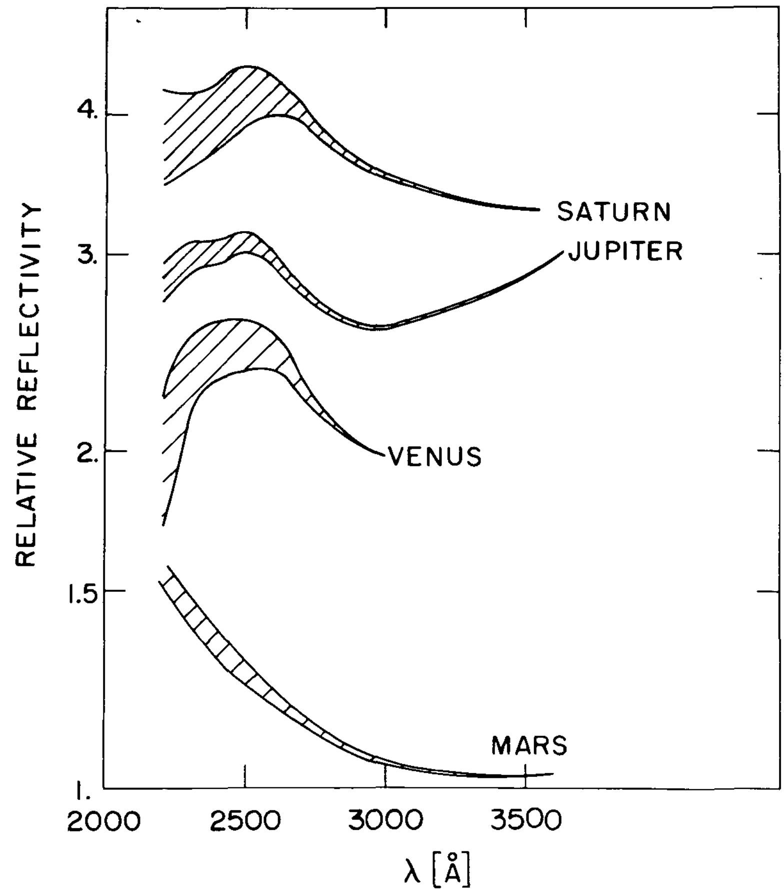

Figure 12.—Relative reflectivities of Venus, Mars, Jupiter and the disk and rings of Saturn. The hatched area at short wavelengths is a measure of the uncertainty of the background correction.

of the solar spectrum instead of Broadfoot's (Wallace 1970; Caldwell 1971) these humps were less pronounced and a depression having at least some of the characteristics of an ozone absorption appeared in the Mars albedo.

To explain the Jupiter hump, Axel (1971) has suggested that the rise in the albedo from ~3000 to ~2500 Å could be due to the increasing importance of Rayleigh scattering. Some absorption beginning at ~2500 Å and increasing to shorter wavelengths could then offset the further increase due to Rayleigh scattering.

The hump in the Venus albedo could have a similar explanation in which HCl might be a candidate for the absorber. CO_2 absorption appears to be responsible for the sharp cutoff below 2100 Å (Anderson et al. 1969) but in view of its lack of influence on the Mars albedo and the discrepancy between different measures of its absorption coefficient above 2000 Å (Shemansky 1972; Ogawa 1971), it is probably not connected with the hump.

The Mars albedo, in contrast to that of Venus, can be explained nicely in terms of Rayleigh scattering by the generally accepted amount of CO_2 (~80 m atm) combined with a general decrease in surface albedo (Caldwell 1971).

The hump in the Saturn reflectivity presents more of a problem since the ground-based observations of Irvine and Lane (1971) given in Figure 6 indicate that longward of about 3600 Å the rings contribute about as much to the reflectivity as the disk and might well contribute more at shorter wavelengths. If that were the case and if the reflectivity of the rings were essentially featureless, any hump in the albedo of the disk would have to be more pronounced than it is in Jupiter in order to show through in the total reflectivity. H_2O crystals now appear to be the best candidate for the ring material (Pilcher, Chapman, Lebofsky and Kieffer 1970), but published measurements of the reflectivity of such crystals (Dressler and Schnepp 1960) do not rule out a hump at the required wavelength. Also, the ground-based spectrometric observations of Younkin and Münch (1963) of Saturn's disk indicate an abrupt upturn in reflectivity at ~3800 Å (see Figure 6) which does not appear to be in conflict with the Irvine and Lane data. The abruptness of the upturn is hard to understand but difficult to dismiss since Jupiter, Uranus and Neptune, observed by Younkin and Münch as part of the same program, show no upturn and their Jupiter results given in Figure 5 are in good agreement with other determinations. Thus it is possible that the disk does dominate over the rings below 3000 Å.

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