OBSERVED ULTRAVIOLET REFLECTIVITY OF MARS

by

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ABSTRACT 22239

Ultraviolet spectrograms of Mars (2400-3500 Angstroms, ~50 Angstrom resolution) have been obtained using an objective grating spectrograph on an Aerobee rocket. The data indicate a reflectivity of 0.04 to 0.08 in the ultraviolet, increasing toward shorter wavelength according to a Rayleigh Law. The data can be represented by an $N_2:CO_2:A$ model atmosphere with a surface pressure of about 15 to 20 millibars. The photographic appearance of the planet in the blue is interpreted as a loss of surface contrast and reflectivity rather than by absorption in the atmosphere by the "blue haze". The model predicts the general appearance of the planet in the photographic ultraviolet, blue, visible, and red. There are serious biological implications since the model predicts that ultraviolet radiation (2000-3000 Angstroms) will reach the surface. *Author*

The Observations: On March 19, 1965, 0300 UT, several spectrograms of Mars were obtained using an objective grating spectrograph, launched from White Sands Missile Range aboard Aerobee NASA 4.57 GG. The camera used in the instrument was designed and manufactured by the Kollmorgen Corporation. It has an effective focal ratio of f/2.11, an effective focal length of 70 millimeters, and can briefly be described as being a modified, wide-field, reflecting microscope objective. It uses spherical, aluminized surfaces; is non-vignetting; and has a calcium fluoride corrector plate. The plane diffraction grating used was 10 centimeters square with 600 lines per milli-meter. A "best fitting" cylindrical film surface was matched to the spherical focal surface of the spectrograph. Eastman Type I-0, 35 millimeter roll film was used to investigate the spectrum of Mars, from 2350 to about 4500 Angstroms. Exposure times for the eight spectrograms were alternately 10 and 46 seconds, with the last one being 35 seconds. The elements of Mars at the time of observation were: true distance from earth, 0.674 AU (Astronomical Units); from the sun, 1.659 AU; semi-diameter, 6.95"; phase angle, 8.14°; illuminated fraction, 0.995. The values used for the distribution of solar energy are based on published information[1-4].

The spectrograms were analyzed with a modified Joyce-Loebl microdensitometer/isophotometer, using both the standard microdensitometer and isophotometer features of the instrument to correct for chromatic abberations in the spectrograph and abberations introduced by using a cylindrical film surface fitted to a spherical image surface. The Mars spectrogram contains the spectrum of β Leo which has been used for an in-flight calibration of the instrument. There is excellent agreement between the stellar calibration of the flight spectrograph and laboratory calibration of three identical spectrographs. The spectrum of β Leo has also

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been used to determine absolute values for the reflectivity of Mars. Values for the ultraviolet spectral intensity of β Leo have been based on the theoretical distribution of intensity of an A3V, B-V = + 0.09, m_v = 2.10 star, correcting for spectral absorption features[5]. The data are presented in terms of geometric reflectivity (i.e. - compared to a Lambert scattering plane surface), not spherical albedo, and apply to the integrated disc of the planet. The resolution of the spectrograms is approximately 50 Angstroms, as determined by the profile of the solar magnesium absorption features at 2800 Angstroms. At this resolution, there are no features in the spectrum which can be attributed to chemical absorptions; thus, the atmosphere can only be analyzed by interpreting the general spectral characteristics.

The best spectrogram is reproduced in Figure 1. The values which have been derived for the spectral reflectivity of Mars are reproduced in Figure 2. The error limits on the derived reflectivity values appear to be less than a factor of 2 (decreasing toward the visible) for the relative reduction, and slightly less for the absolute determinations derived by comparison to β Leo. The error limits refer to the degree of confidence in the data reduction of the best spectrogram. They are not quantitatively derived. In Figure 2 are also reproduced the geometric reflectivity values determined by ground based observers, and summarized by deVaucouleurs[6], and the 2700 Angstrom value determined by Boggess and Dunkelman as a result of a rocket flight in 1957[7].

The relative value curve for the geometric reflectivity of Mars (Figure 2) is normalized to the ground based value of 0.04 at 3500 Angstroms. The absolute values were determined and plotted independently. There is extremely close agreement of these two methods in producing reflectivity values in the 2500- 3000 Angstrom range.

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Interpretation: In order to derive a value for the optical depth and therefore surface pressure of the Martian atmosphere from the observed reflectivity spectrum, the atmospheric scattering properties and surface reflectivity of Mars must be considered.

Values for geometric reflectivity from model atmospheres with Rayleigh scattering can be derived and compared to the Martian ultraviolet spectrum. Reference (8) contains the reflectivity values for a plane parallel atmosphere with Rayleigh scattering for 0.0, 0.25, and 0.80 surface reflectivity. The reflectivity values of a spherical atmosphere can be approximated by placing a plane parallel atmosphere tangent to each point of the surface, and projecting onto a circular disc. Because of the low reflectivity of Mars in the 3000 to 4000 Angstrom region of the spectrum, the 0.0 surface reflectivity model was chosen. Table 1 represents the integrated geometric reflectivity values from a planet with a Rayleigh scattering atmosphere, zero phase angle, and zero surface reflectance for seven different optical depths.

Table 1

Geometric Reflectivity from a Spherical Planet with Rayleigh Scattering; Zero Phase Angle; Zero Surface Reflectivity

Normal Optical Thickness	Integrated Reflectivity
0.02	0.014
0.05	0.033
0.10	0.064
0.15	0.095
0.25	0.137
0.50	0.235
1.00	0.367

In order to assign wavelengths to the various optical thicknesses, it is necessary to compute the Rayleigh scattering properties of model atmospheres. This work has been done by Coulson and Lotman[9] for a model atmosphere of Mars having a composition of 94% N_2, 4%A, and 2% CO_2, with

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pressure of 85 millibars. They present their results in terms of normal optical depth versus altitude for wavelengths above 2000 Angstroms. By selecting their results for different altitudes it is possible to determine the scattering properties of atmospheres with surface pressures from 4 to 85 millibars for an atmosphere consisting mainly of nitrogen.

At any specific wavelength there is a relationship which exists between optical depth, τ, index of refraction, n, number of particles per unit volume, N, ... molecular weight, m, and the derived surface pressure, P_S, for any combination of Rayleigh scattering particles. The relationship, reduced to its simplest form is

$$P_S\,(CO_2)=P_S\,(N_2)\; X\; \frac{(n-1)^2_{N_2}}{(n-1)^2_{CO_2}}\; X\; \frac{m_{CO_2}}{m_{N_2}} = 0.68\; P_S(N_2), \quad (1)$$

and is approximately independent of wavelength in the spectral region being considered. The relationship between surface pressure, composition, and optical depth is presented in Table 2.

Table 2

Correspondence of Wavelength and Optical Thickness: Rayleigh Scattering Atmosphere, Zero Phase Angle, Zero Surface Reflectivity

Normal Optical Thickness, τ	or CO2 3 mb / N2 4 mb	Surface Pressure (mb, millibars)			
		6 mb / 9 mb	14 mb / 21 mb	31 mb / 45 mb	58 mb / 85 mb
0.02	2650A	3300A	4000A	4800A	5600A
0.05	2150	2650	3250	3900	4500
0.10	<2000	2250	2750	3300	3800
0.15		2025	2500	2950	3450
0.25		<2000	2200	2625	3050
0.50			<2000	2200	2600
1.00				<2000	2200

Using tables 1 and 2, it is possible to determine values of

geometric reflectivity as a function of wavelength, as shown in Figure 3. The reflectivity of Mars in the ultraviolet can therefore be interpreted in terms of surface pressure.

The amount of CO_2 in the atmosphere of Mars is approximately 45 meter-atmospheres (Ref. 10b, c; 11). This corresponds to a surface partial pressure of CO_2 of about 3 millibars. Since the atmosphere is thin, the reflectivity of the constituents will be directly additive. Therefore, the reflectivity from non-CO_2 sources is almost identical with the 9 mb N_2 curve for geometric reflectivity below 3000 Angstroms. Assuming that N_2 is the major remaining constituent, and that all the reflectivity is due to Rayleigh scattering then the total surface pressure will be about 12 millibars. The error introduced by instrumental calibration and data reduction is about $\pm$ 5 millibars for this total pressure.

There are several factors which can influence the value determined for surface pressure by the scattering technique. Any contributing reflectivity from clouds, haze[12], or the surface will lower the reflectivity attributed to Rayleigh scattering, and thus decrease the proposed pressure value. If the "blue haze" were an absorbing layer[13, 14] or opaque reflecting layer, the Rayleigh reflectivity would represent a pressure at the top of this layer. If there were absorbing components such as N_2O_2 and NO_2 in the atmosphere, distributed with altitude which prevented ultraviolet radiation from reaching the surface, then the derived pressure value would be a lower limit for the surface pressure.

The ultraviolet spectral profile supports the idea that the atmosphere is transparent in the ultraviolet. There are no detectable absorption features in the 2400 to 3500 Angstrom spectral region, indicating that there are no

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significant amounts of ultraviolet absorbers such as ozone or $N_2O_2:N_2$ [10e, 15] in the atmosphere. This indicates that the "blue haze" is not an absorbing component of the atmosphere.

In the ultraviolet it is likely that the reflectivity of the surface must be at least 0.01 or 0.02 since naturally occurring substances are not usually black in that region of the spectra. Even gold black and carbon suspended in oil reflect significantly in the ultraviolet, 0.003 [16]. The reflectivity of most naturally occurring materials found on earth, especially rocks and large scale landscapes (not necessarily including vegetation) decrease from red to blue, being generally lower than 0.1 by 4000 to 4200 Angstroms, especially desert regions [17, 18]. The reflectivity of the moon is about 0.06 [19] in the photographic ultraviolet. It would not be unreasonable to expect the ultraviolet reflectivity of the surface of Mars to be in the 0.01 to 0.02 range. Beside indicating a low reflectivity for Mars, using the comparison of the earth and moon, there is the simultaneous inference that the contrast of surface features will be reduced, and easily obscured by any reflectivity due to the atmosphere above the surface. Thus, a major portion of the featureless appearance of Mars in the ultraviolet can be explained by a loss of reflectivity and contrast of the features themselves.

This does not however, preclude the presence of actual hazes or clouds of large particles. In fact, the "blue-clearings" do indicate the presence of such a haze [14, 17, 20]. The haze would be required to be very thin and tenuous because the total reflectivity of the planet in the 3000 to 4000 Angstrom region of the spectrum is only ~0.04. The amount of water present in clouds of 0.01 to 0.02 reflectivity, if they are indeed water, would be well below the limit of detectability from earth [10, 11, 21, 23]. The data is therefore not inconsistent with water clouds. The Martian

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clouds should be easily observable when the surface
reflectivity dropped to values of ~0.05 or lower. They
should be observed mainly in blue and ultraviolet photographs
since it is in those spectral regions where the surface
reflectivity is low. Surface features of low reflectivity
and contrast would be further obscured by such a haze or
cloud, even if it has a very low reflectivity. Features
of high reflectivity, 0.10-0.20, in the blue and photographic
ultraviolet should be observed in the photographs of the
planet, even through the thin haze. The polar cap, a snow
or frost feature, has such a high reflectivity, independent
of wavelength, and is indeed observed in blue and ultraviolet
photographs[14, 17, 20].

The derived pressure range of 10 to 20 millibars is
likely to be an upper limit because the atmosphere appears
to be relatively transparent, as indicated by low reflectivity
and absence of absorption features in the ultraviolet,
combined with the visibility of the polar cap in blue and
ultraviolet photographs. A lower limit cannot be definitely
assigned because the exact values of reflectivity of the
surface and the "blue haze" are not known. The reflectivity
of 0.04, at 3400 Angstroms, consists mainly of reflection
from the surface and the haze. The haze reflectivity should
change slowly with wavelength and the surface reflectivity
is likely to decrease toward shorter wavelengths. A
realistic value of the non-Rayleigh reflectivity at 2500
Angstroms would be about 0.02. The lower limit for the
pressure values would then be about 5 to 15 millibars, 10
millibars being most likely. The pressure values are
summarized in Table 3.

Table 3

Atmospheric Parameters of Mars Determined from the Ultraviolet Reflectivity

Amount (meter atmospheres NTP)			Surface Pressure millibars
Pure CO_2	Pure N_2	N_2 (with 45m-atm. CO_2) (ref. 10b,c; 11)	
66	104	32	5 lowest limit
132	208	136	10 most probable
198	312	240	15
274	416	344	20 highest limit

Calculations based on the Rayleigh scattering tables[8] predict that the central reflectance due to scattering from a 10 millibar atmosphere should be about 0.01 and the limb reflectance should be about 0.05 in the 4500-5000 Angstrom spectral region. At shorter wavelengths the center to limb contrast due to Rayleigh scattering should decrease while the limb reflectivity should steadily increase to 0.10 or 0.15 (in the photographic ultraviolet). This predicts that the polar cap should become less distinct in the ultraviolet due to loss of contrast, (i.e. the atmospheric reflectivity equals or exceeds the reflectivity of the polar cap). This effect can apparently be seen in published photographs of Mars[17, 20]. In the red, a gradual limb darkening is inferred by similar calculations from the Rayleigh scattering tables. This darkening occurs because the surface reflectivity is high in the red spectral regions. The effect of the atmosphere at the limb is to scatter light from the observational path instead of increasing the brightness, as the case when there is low surface reflectivity. The limb should be slowly darkened, rather than be dark just at the edge. Again, this effect is apparent in the observational data[17, 20].

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The scattering due to a _thin_ haze will cause similar effects, but computations of the effect have not been made. The surface reflectivity and total reflectivity of Mars is highest in the red region of the spectrum. It is relatively safe to assume that the reflectivity of the polar cap is a constant, not a function of wavelength (by comparison to H_2O CO_2, and similar "frosts" on the earth). The contrast between the "light areas" and the polar cap will be decreased in the red spectral region. Limb darkening in the red will tend also to reduce the contrast. Since the predictions based on a 10 to 20 millibar surface pressure model for Mars are borne out by observed characteristics from ground based observations, the credibility of the low pressures is improved. Recent work by other experimenters indicates that pressures of 10 to 20 millibars would apply to the surface of Mars[10a-e, 11]. The determination of pressure of Ref. 11 is based on photographic infrared spectrograms, and thus can be attributed to the surface since the atmosphere is transparent in that spectral region.

Conclusion

The spectrum of Mars can be divided into several regions where different effects are important in producing the reflectivity of the entire planet. Below 3000 Angstroms Rayleigh scattering, large-particle scattering, and reflection from the surface are all important, with Rayleigh scattering beginning to predominate at shorter wavelengths. In the 3000-4000 Angstrom range, Rayleigh scattering should contribute about 0.01 to the total reflectivity, large-particle scattering 0.01-0.02, and surface reflectivity about 0.01-0.02. The reflectivity of the polar cap should be approximately constant at all wavelengths at about 0.15 to 0.25 (i.e. slightly higher than the light areas in the red region of the spectrum). The contrast of surface features

should be reduced essentially to zero in the 3000-4000 Angstrom range. Maximum limb brightening should occur at 4500 to 5000 due to Rayleigh scattering. Between 4000-5000 Angstroms, the increasing reflectivity of the surface should begin to predominate in determining the total reflectivity. The contrast of surface features should rapidly become apparent. Above 5000 Angstroms, where the reflectivity of the surface predominates, limb darkening should become apparent. All of these effects can be observed in photographs of the planet Mars.

The appearance of the planet in different colors can be satisfactorily described without postulating atmospheric absorbers in the blue and ultraviolet. The 10 millibar model can be used to determine the ultraviolet flux at the surface of Mars. Assuming a ten times larger than possible oxygen concentration of 70 centimeter-atmospheres[10b], the model infers that the transmission of direct solar radiation to the surface, at 60° solar zenith angle, will be about 70% at 2000 Angstroms (correcting for both scattering and oxygen absorption). Between 2000 and 3000 Angstroms, approximately 90% of the direct solar radiation should reach the surface. There will be serious biological effects caused by such high intensity radiation. Studies of the germicidal effects of ultraviolet radiation[24,25] indicate that a lethal exposure to the radiation would be accumulated in one or two days for almost all types of bacteria, spores, fungi, viruses, protozoans, etc. found on earth.

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LEGENDS

Figure 1 - Mars Spectrogram. The zero order image and spectra of Mars are contained within the spectrogram. The spectra of ρ Leo is present, with the zero order image outside the film format. The peculiar shape of the zero order images is due to rocket motion during the 45 second exposure. There is noticeable contrast loss in the reproduction below 2800 Angstroms

Figure 2 - The geometric reflectivity of Mars. Solid Line: Relative Data normalized at 3400 Angstroms. Pluses: Absolute reflectivity determined by comparison to ρ Leo, plotted independently. The dashed lines below 3400 represent the error range applied to the relative data. X?: Ref (7). Open Circles: Ref (6).

Figure 3 - Geometric reflectivity of model atmospheres of Mars as a function of wavelength and surface pressures. See text for more details.
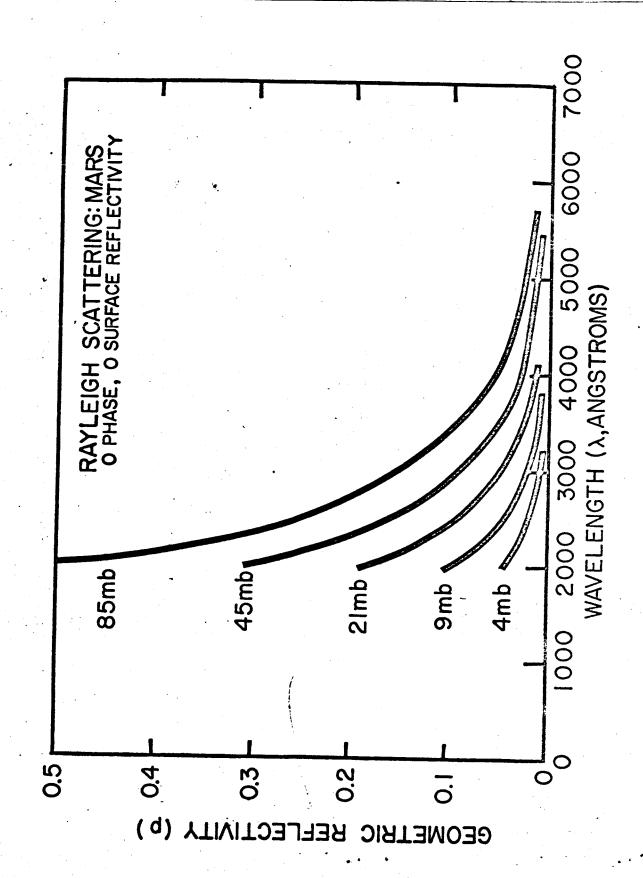
FIGURE I: MARS SPECTROGRAM

β LEO SPECTRUM

| | | | |
2000 2500 3000 3500

α LEO

ρ LEO

MARS SPECTRUM

| | | | |
2000 2500 3000 3500
WAVELENGTH, λ ANGSTROMS

MARS

RAYLEIGH SCATTERING: MARS
O PHASE, O SURFACE REFLECTIVITY

85mb

45mb

21mb

9mb

4mb

GEOMETRIC REFLECTIVITY (p)

0.5

0.4

0.3

0.2

0.1

0

WAVELENGTH (λ, ANGSTROMS)

0   1000   2000   3000   4000   5000   6000   7000

GEOMETRIC REFLECTIVITY OF MARS
FLIGHT DATA:—RELATIVE
++ABSOLUTE(β LEO)

GEOMETRIC REFLECTIVITY (ρ)

WAVELENGTH (λ,ANGSTROMS)

X?