No. 104 NEW MULTICOLOR FILTER PHOTOMETRY OF MARS

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ABSTRACT

New photometry of Mars for the wavelength region 0.33 – 5.0 μ with broad and medium-narrow filters is presented. The observations show a variation of 10 percent in whole-disk reflectivity in the 1 μ region. The reflectivity of Mars is found to decrease between 2.2 and 3.5 μ. The integrated albedo is found to be 0.31 ± .03 pe. The apparent 5 μ brightness temperature is 243° K for the 1967 opposition period.

1. Introduction

During the course of our multicolor photometric observational programs (Johnson, *et al,* 1966), we obtained observations of planets and satellites over the entire wavelength range from 0.3–5.0 μ. This paper gives the observations for the planet Mars. Discussions of observations for Venus and Mercury are now in preparation.

In recent years the geometric reflectivity of Mars has been computed from observations made with spectral scanners covering the spectral region 0.3–1.2 μ. In the region 0.8–1.2 μ, a depression in the reflectivity has been interpreted as due to limonite (Younkin 1966). Tull (1966) found an even stronger effect in his spectral scans in this region. Sinton's (1967) scans, however, confirmed Younkin's data indicating a small limonite spectral effect. Our multicolor (broad and narrow-band) photometry appears to confirm the difference between Tull and Younkin, in that variations are observed at 1 μ.

In the 1–4 μ region, the spectrum and the reflectivity of Mars have been studied by Moroz (1964) and Sinton (1967). Of specific interest here is their interpretation of a dip in reflectivity at 3 μ as due to water of hydration.

Our 5 μ data introduce new information about the thermal emission of Mars. The mean Mars disk temperature from 10 μ brightness measures (Pettit and Nickolson 1924; Menzel, Coblentz, and Lampland 1926; and Sinton and Strong 1960) are combined with these new 5 μ observations in the discussion of the thermal emission of Mars.

2. Observations

Because of the large image size of Mars and the fixed diaphragm size of the JHKLM photometer (Johnson and Mitchell 1962), the far-infrared observations were made on the 21-in. and 28-in. telescopes. When used with these two telescopes, the diaphragm of the JHKLM photometer is large enough to include the entire disk of Mars. A few UBVRI observations were obtained simultaneously with the JHKLM measures. These observations are listed in Tables 1 and 2. The last column for the JHKLM observations lists the probable error of the mean M magnitude, which was obtained from the repeated M deflections at the 21-in. telescope. α Boo was used as the M (5 μ) standard. The M measures reported here were made with the JHKLM photometer, which has a liquid-nitrogen-cooled PbS cell as detector.

TABLE 1
JHKLM PHOTOMETRY OF MARS

JD	MERIDIAN	K	J − K	H − K	K − L	K − M	TELESCOPE	PROBABLE ERROR OF M
38818.964	201°	—3.24	+0.24		—0.43		28"	
38826.843	89	—3.39	0.19		—0.45		28	
39602.808	170	—3.70	0.34	+0.01	—0.45	+0.90	28	
39603.744	142	—3.76	0.36	—0.02	—0.44	0.92	28	
39604.734	130	—3.74	0.43	—0.01	—0.47	0.85	28	
39648.700	83	—2.78	0.31	+0.02	—0.51	1.02	21	± 0.10 mag
39649.664	61	—2.66	0.32	—0.01	—0.45	1.16	21	± 0.08 mag
39650.626	38°	—2.68	+0.25	+0.01	—0.32	+1.19	21"	± 0.10 mag

TABLE 2
UBVRI PHOTOMETRY OF MARS

JD	MERIDIAN	V	U − V	B − V	V − R	V − I
38818.942	193°	—1.08	+1.90	+1.33	+1.24	+1.69
38826.795	72	—1.35	1.83	1.29	1.10	1.64
39603.758	143	—1.70	1.93	1.35	1.23	1.75
39604.761	136°	—1.57	+1.93	+1.35	+1.24	+1.79

TABLE 3
8-COLOR PHOTOMETRY OF MARS

JD	MERIDIAN	33 − 52	35 − 52	37 − 52	40 − 52	45 − 52	52 − 58	52 − 63
39641.701	148°	+1.251	+1.191	+1.479	+1.448	+0.593	+0.900	+1.432
39642.687	134	1.263	1.206	1.491	1.451	0.631	0.887	1.414
39649.608	41	1.211	1.170	1.433	1.403	0.600	0.818	1.280
39653.729	47	1.126	1.083	1.344	1.361	0.587	0.810	1.290
39663.670	289°	+1.362	+1.284	+1.498	+1.462	+0.615	+0.811	+1.282

TABLE 4
6-RC PHOTOMETRY OF MARS

JD	MERIDIAN	58 − 72	58 − 80	58 − 86	58 − 99	58 − 110
39622.750	337°	+0.799	+1.019	+1.084	+1.250	+1.401
39624.788	332°	+0.791	+1.047	+1.115	+1.317	+1.498

TABLE 5
6-RC PHOTOMETRY OF SOLAR TYPE STARS

STAR	SP	58 − 72	58 − 80	58 − 86	58 − 99	58 − 110
β Com	Go V	+0.326	+0.472	+0.538	+0.599	+0.677
β Com	Go V	0.327	0.471	0.522	0.589	0.733
λ Ser	Go V	+0.329	+0.490	+0.553	+0.598	+0.720

TABLE 6
MEAN 13-COLOR PHOTOMETRY

	33 − 52	35 − 52	37 − 52	40 − 52	45 − 52	58 − 52	63 − 52	72 − 52	80 − 52	86 − 52	99 − 52	110 − 52
Sun	+0.356	+0.328	+0.621	+0.730	+0.277	−0.314	−0.513	−0.642	−0.792	−0.852	−0.909	−1.025
Mars	+1.243	+1.187	+1.449	+1.425	+0.605	−0.845	−1.340	−1.641	−1.878	−1.944	−2.129	−2.295

TABLE 7
MEAN UBVRIJHKLM PHOTOMETRY

	U − V	B − V	V − R	V − I	V − J	V − H	V − K	V − L
Sun	+0.70	+0.64	+0.52	+0.78	+1.06	+1.34	+1.41	+1.53
Mars	+1.90	+1.34	+1.23	+1.72	+1.80	+2.11	+2.11	(+1.61)

In addition to the broad-band observations, a few medium-narrow-band observations on our new 13-color system were obtained. Eight of these colors were observed with a 1P21; observations of 985 bright stars on the eight-color system have been published by Johnson, Mitchell, and Latham (1967). The other five colors, observed with a 7102 (the 6-RC system), are given here in preliminary form; the zero point of the colors is 0.00 for α Lyrae. These observations are given in Tables 3, 4, and 5.

Tables 6 and 7 list the mean observed colors of Mars and the derived colors of the Sun. The solar UBVRIJHKL values are taken from H. L. Johnson (1965), and the solar 8-C colors are those used in the absolute calibration of the medium-narrow filter photometry (Johnson, Mitchell, and Latham 1967). The 6-RC solar colors are derived from Table 5. The mean V − L given refers to the reflected solar energy; the observed K − L was corrected by −0.06 mag to account for the 250° K blackbody emission of Mars in the L filter.

3. *Geometric Albedo*

Following the analysis of Harris (1961) we adopt a mean unit distance brightness for the V-mag system (V = −1.52). We assume that the mean colors are independent of phase. M (5 μ) is treated separately.

The geometric albedo plotted in Figure 1 was computed at each wavelength according to the usual formula (Harris 1961), using de Vaucouleurs' (1964) planetary dimensions and H. L. Johnson's

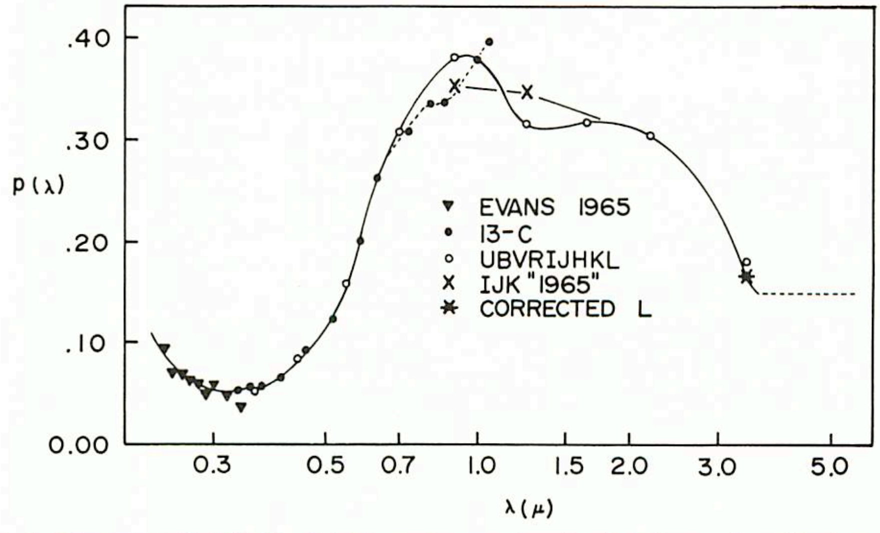

Fig. 1 The geometric albedo of Mars versus wavelength plotted on a logarithmic scale.

(1965) solar values. Evans' (1965) Aerobee data have been scaled to match our data near 0.33 μ. The far-infrared reflectivity has been tied to the visual reflectivity by simultaneous observations in the visual and the infrared.

Three separate curves are given in Figure 1 near 1 μ. The values from the 6-RC photometry are near the Martian meridian, (354°) observed by Tull (1966). The smooth UBVRIJHKL curve is an average of values around 150° and 50° The third curve indicates I and J from 1965 observations, relative to the mean K value of the above curve. This last curve appears flat, like the spectral scans near meridian 30° by Younkin (1966) and 270° by Sinton (1967). These data indicate that real variations of 10 percent in reflectivity for the disk are present in the 1 μ region; with other published data, they indicate that the primary effect is related to the central meridian observed. Phase and seasonal effects are also present. This variation, in the region of the limonite absorption band, might be interpreted in terms of mineral distribution as discussed by Binder and Cruikshank (1966), Moroz (1964), and the other authors cited in this paragraph.

This variation in Martian reflectivity near 1.0 μ can be shown in another way independent of our solar calibrations. Sinton (1967, Fig. 3) used β Com as a solar-like comparison star; our analysis of the 6-RC photometry also strongly depends on β Com as a comparison star. The comparison of Sinton's results with ours, both using β Com as a reference, shows the reality of these variations.

4. *Integrated Bond Albedo*

The total Bond albedo is defined as:

$$A = \int_0^\infty p(\lambda)q(\lambda)S(\lambda)d\lambda \bigg/ \int_0^\infty S(\lambda)d\lambda.$$

Where

$p(\lambda)$ = the geometric albedo (Fig. 1);

$q(\lambda)$ = the phase integral (de Vaucouleurs 1964, case *b*);

$S(\lambda)$ = the solar spectrum. The spectrum used was the average of Allen's 1963 spectrum with the solar central intensity data of Labs and Neckel (1967) corrected for limb darkening.

The derived total albedo is 0.31 ± .03 pe. The principal source of error is the phase function and its integral in the infrared. An additional source of error is the variation of color and brightness with the Martian central meridian. Using this total albedo, the solar constant, 1.37×10^6 erg/cm^2 sec, and the semimajor axis of the orbit of Mars, 1.5237 AU, the total energy absorbed by Mars is 0.40×10^6 erg/cm^2 sec. This surface flux corresponds to a blackbody temperature of 291° K, in good agreement with the observed brightness temperature at 10 μ for the subsolar point on Mars as given by Sinton and Strong (1960) and others.

5. *5 and 10 μ Thermal Energy*

The M (5 μ) photometry was observed at two epochs, April (near opposition) and June. Using Johnson's (1965) calibration and assuming that all the radiation is thermal emission, the brightness temperature is computed to be 248° K for April and 243° K for June. The temperature is lower in June when more of the cool morning edge is seen. If allowance is made for reflected solar radiation (assuming $p(\lambda) = 0.15$ at 5 μ, which is slightly less than $p(\lambda) = 0.17$ determined at 3.4 μ), the computed April opposition thermal radiation is 0.86 W/cm^2 cm at 5 μ; this corresponds to a brightness temperature of 243° K. Because the solar flux at the surface of Mars is about twice the observed 5 μ flux at the surface, this interpretation of the M photometry would be questionable except for the fact that the Martian reflectivity is observed to fall off sharply between 2.2 and 3.4 μ.

Published 10.2 μ data on Mars include few whole-disk observations because of image-size limitations. The scan data published by Sinton and Strong (1960) were integrated and 252° K was found for the Mars disk. Pettit and Nicholson (1924) published 250° K as a mean disk brightness temperature. For observations in 1924, the mean disk brightness of 246° ± 4° pe was obtained by Menzel, Coblentz, and Lampland (1926). Since these three independent references for 10 μ photometry have also shown local 10 μ brightness variations (including latitude, longitude, and Martian season), it appears reasonable to assume 250° ± 4° pe for the disk 10 μ brightness temperature.

Figure 2 shows the energy spectrum of Mars for each component of the radiation. The energy from solar reflection and from Mars thermal emission appear to be equal at about 4.2 μ.

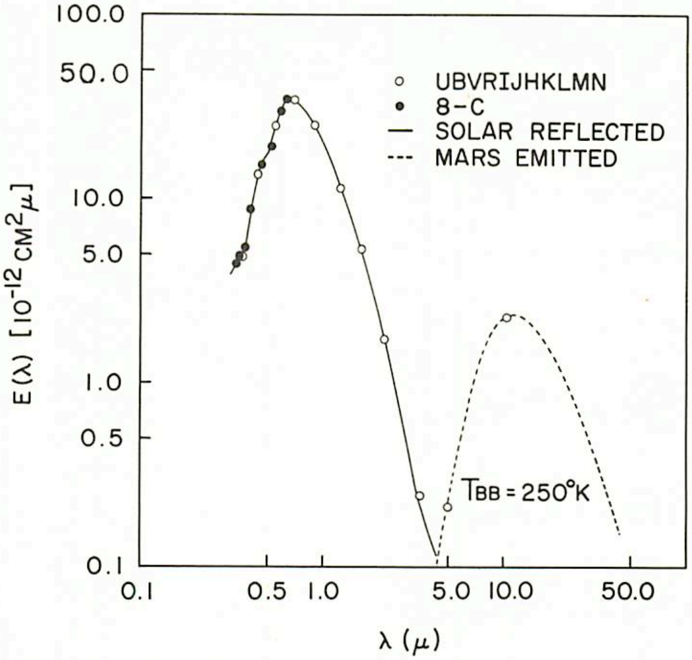

Fig. 2 The observed energy received at the earth from Mars, reduced to mean opposition. The two curves show the reflected and emitted radiation.

6. Summary

Following the discussion by Blanco and McCuskey (1961) and using the integrated Bond albedo, the energy absorbed by Mars is computed; the equivalent blackbody temperature obtained is 291° K. The mean surface brightness temperature for an illuminated insulated hemisphere is 245° K; for a perfect conducting or rapidly rotating sphere reradiating into 4 π steradians, it is 206° K.

From a comparison of the 5 and 10 μ brightness temperature with the simple insulated hemisphere model, it is concluded that a blackbody temperature of 245° K is appropriate for the significant thermal radiation from Mars. In Figure 2, more than 90 percent of the thermal radiation for Mars is radiated at wavelengths shorter than 40 μ, with half the energy short of 17 μ. The emissivity at 5 μ is near unity ($\geqslant$ 85 percent). The emissivity at 10 μ is seen to be near unity since the subsolar point 10 μ brightness temperature is the same as the absorbed solar-flux temperature. It follows that the emissivity is near unity at wavelengths longer than 10 μ and that the brightness temperature at these wavelengths must be near 245° K; otherwise the 5 and 10 μ brightness temperatures and the color (5 μ and 10 μ) temperature would not correspond to the simple hemispherical temperature within their probable errors.

Finally, the mean brightness temperatures of a rapidly rotating sphere may be compared with the radio centimeter brightness temperature of 200° K. The radar measures indicate 89 percent emissivity (a survey of radio observations of the planets by Kellerman 1966). It appears that the time required to conduct thermal energy to an optical depth sufficient to produce radiation in the centimeter region is several revolutions. The simplest model accounts for all the observed radiation from Mars in both the infrared and radio regions; thus, within the errors of these observations, the absorbed solar energy accounts for all the observed energy.

The analysis given here must be considered preliminary as only a few faces of the planet have been examined in the far infrared. Because of the nearly equal rotation periods of Mars and earth, it is difficult to determine the phase functions and phase integrals free of longitude effects from just one opposition. For this reason we propose to observe Mars through several oppositions.

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