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Mars: Measurements of its Brightness Temperature at 1.85 and 3.75 cm Wavelength

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New measurements of the microwave temperature of Mars are reported. The brightness temperatures measured during the planet's close approach in 1967 were 182° ± 15°K (m.e.) at 1.85 cm, and 200° ± 11°K (m.e.) at 3.75 cm.

INTRODUCTION

It is well known that information regarding certain physical properties of the Martian epilith can be deduced from the spectrum of the microwave brightness temperatures (see, e.g., Morrison, Sagan, and Pollack, 1969; Troitskii, 1970). In particular, the slope of the Martian radio spectrum shortward of a few centimeters wavelength is determined in most thermophysical models by two parameters, the microwave emissivity and δ, the ratio of the electrical to thermal penetration depths in the planet's epilith. In general, both parameters vary with wavelength. Attempts to assemble the existing data into a well-defined spectrum have been only marginally successful, and the need for additional, adequately calibrated measurements has often been cited. In response to this need I measured the Martian brightness temperature at two wavelengths, 1.85 and 3.75 cm, during the planet's close approach in the Spring of 1967.

OBSERVATIONS

The measurements were made with the University of Michigan 85-ft, equatorially mounted, radio telescope on five nights when the weather was clear and calm. The half power beamwidth of the antenna is 3.′1 at 1.85 cm and 6.′0 at 3.75 cm. The receivers were Dicke-type radiometers with broad band tunnel-diode amplifiers; the bandwidth at 1.85 cm (16.2 GHz) was 2 GHz and that at 3.75 cm (8.0 GHz) was 1 GHz. The standard deviation of the receiver noise fluctuations measured with one-second integration periods was 0.20°K at 1.85 cm and 0.08°K at 3.75 cm.

A typical measurement of Mars consisted of five right ascension scans of the antenna beam across the planet, five declination scans, and a series of eight on–off measurements. The scan data were used to calibrate and minimize the antenna pointing errors. Each sequence, requiring approximately one hour to complete, produced a signal-to-noise ratio greater than 25. The receiver gain was calibrated with the noise from an argon discharge tube every half hour. During the observations, the outputs from the receiver and the telescope-position encoders were digitized and recorded on magnetic tape after each 2-sec integration period.

Interspersed among the observations of Mars were similar measurements of the comparison radio sources Virgo A, Hydra A, and the quasi-stellar source 3C273. Hydra A was not observed at 1.85 cm because its signal-to-noise ratio was very low. Because 3C273 is a radio variable, it was used only to calibrate the hour-angle dependence of the antenna gain. The declinations of 3C273 and Mars differed by less than 10° at the time of the Mars observations. The dependence of antenna gain on zenith angle measured along the

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meridian has been calibrated at 3.75 cm (Klein, 1968), and I have estimated a similar dependence at 1.85 cm. All measured antenna temperatures were normalized to their hypothetical values at the zenith. The uncertainties in this normalization procedure are less than 1% at 3.75 cm, and less than 3% at 1.85 cm.

A comparison of the response widths of the scans of Virgo A and 3C273 at the two wavelengths reveal that the angular diameter of Virgo A is smaller at 1.85 cm than at 3.75 cm. From the widths of the Gaussian curves which were fitted to the data, it was concluded that the diameter of the Virgo A source at 1.85 cm is approximately $\frac{1}{3}$ arc-min. To account for the partial resolution of the source by the 3.′1 beam, the antenna temperatures of Virgo A were increased by 1%. Because the response widths of Virgo A and 3C273 at 3.75 cm agreed with those measured by Dent and Haddock (1966), their values of the resolution correction factors for Virgo A and Hydra A were adopted. Consequently, the 3.75-cm antenna temperatures of these two sources were increased by the factors 1.04 and 1.01, respectively.

Because the antenna feed horns respond to only one plane of polarization of the incoming signal, an additional correction factor must be applied to the measurements to account for the linear polarization of Virgo A and Hydra A. Following Dent and Haddock (1966), the measured antenna temperatures were multiplied by the factor $C_p = [1 + P\cos 2\theta]^{-1}$, where P is the degree of linear polarization and θ is the difference between the position angle of the plane of the source polarization and the plane of polarization accepted by the antenna. Using the polarization measurements of Aller (1970) at 3.75 cm, the values obtained were $C_p = 1.014$ for Virgo A and $C_p = 1.01$ for Hydra A. Because there was evidence that the percent of linear polarization of Virgo A might increase with frequency (Allen, 1966), polarization measurements of this source were made by W. A. Dent and myself at 1.85-cm wavelength during June and July, 1967. The 1.85-cm feedhorns were replaced with a polarimeter that consisted of a continuously rotated feed horn and a fixed reference horn. The polarimeter, scaled in size according to the wavelength ratio, and the observing procedure were similar to those described by Aller (1970). The instrumental polarization was calibrated by observing the thermal radio source M17 (the Omega Nebula), which we assumed to be unpolarized. It was concluded from our results that the degree of linearly polarized flux of Virgo A at 1.85 cm wavelength is 2.5 ± 1% at position angle 56° ± 10°; the corresponding values at 3.75 cm are 1.40 ± .04% at position angle 86° ± 1° (Aller, 1970). The uncertainties are mean errors which include the uncertainty in the calibration of the instrumental polarization. Based on these results a polarization-correction factor of 1.01 was adopted for Virgo A at 1.85 cm.

The Martian flux density on each of the five nights was calculated from the measured ratios of the adjusted antenna temperatures of Mars, Virgo, and (at 3.75 cm) Hydra A. The following flux densities were assumed for the comparison sources: 49 flux units (1 flux unit $= 10^{-26}$ W m^{-2} Hz^{-1}) for Virgo A at 3.75 cm, 28 flux units at 1.85 cm, and 8.75 flux units for Hydra A at 3.75 cm. These values are consistent with the flux scale of Kellermann, Pauliny-Toth, and Williams (1969) and of Scheuer and Williams (1968). The flux densities of Mars at 1.85 cm measured on April 28 and May 21, 1967, are 6.66 and 5.01 flux units, respectively; the 3.75 cm flux densities measured on April 12, May 3, and May 12, 1967 are 1.68, 1.74, and 1.47 flux units, respectively.

RESULTS AND CONCLUSIONS

The Martian brightness temperatures were calculated from the flux densities in the usual manner. The resulting temperatures and corresponding mean errors are listed in Table I for each of the five nights. Each individual temperature was weighted inversely proportional to the square of its mean error, and the average temperatures were calculated for the two wavelengths. These weighted averages appear in their respective columns. The statistical scatter

TABLE I

SUMMARY OF OBSERVATIONS

Date (1967)	Brightness temperature (λ = 1.85 cm)	Date (1967)	Brightness temperature (λ = 3.75 cm)
April 28	187° ± 5°K	April 12	201° ± 5°K
May 21	175° ± 6°K	May 3	206° ± 7°K
		May 12	190° ± 7°K
Weighted average	182°K	Weighted average	200°K
Internal uncertainty	±7°K	Internal uncertainty	±4°K
Total uncertainty	±15°K	Total uncertainty	±11°K

in the data was combined with the uncertainties in the various instrumental correction factors in order to determine the internal uncertainties listed below the average temperatures. The total uncertainty, in addition to the above, includes the probable errors associated with the flux densities of the principle calibration source, Virgo A. Note that no attempt was made to normalize the temperatures to a particular Mars–Sun distance since the normalization depends, to some extent, upon the thermophysical model of the Martian epilith.

The 3.75-cm brightness temperature reported in this paper can be directly compared with that measured by Dent, Klein, and Aller (1965) because the same calibration source, Virgo A, was included in both observing programs. However, the flux density assumed for Virgo A in the 1965 publication is lower than the currently accepted value, and consequently, the published value of the Martian brightness temperature should be increased by 9%. The adjusted value of the 3.75-cm Martian temperature measured in 1965 is 198° ± 4°K; the temperature measured in 1967 is 200° ± 4°K. Note the close agreement within the quoted errors which correspond to the 1-σ internal uncertainties of both measurements.

Nearly equal temperatures are expected because the latitude of the subearth point on Mars remained between +20° and +24° during both sets of measurements, and the solar distance of Mars at the time of the 1965 opposition was only 4% greater than the corresponding distance in 1967.

The two brightness temperatures measured in 1967 are in good agreement with previously published data, which indicate that the Martian brightness temperature at wavelengths between 1 and 21 cm is approximately 190°K (Hobbs, McCullough, and Waak, 1968). The weighted average of the 1.85- and 3.75-cm temperatures reported in this paper is 193° ± 10°K. By themselves, the two individual temperatures provide little information about the temperature gradient between the two wavelengths because the uncertainties of the measurements are relatively large. According to the models computed by Morrison, Sagan, and Pollack (1969), the predicted brightness temperature at 1.85 cm is less than 10°K warmer than the 3.75-cm temperature for plausible values of δ. However, these new measurements should help define the microwave spectrum of Mars more accurately. The importance of determining the radio spectrum has recently been emphasized by Epstein (1971), who suggests that measurements of the brightness temperature at millimeter wavelengths do not tend to conform to the spectra predicted by theoretical models. Thus the proper interpretation of the microwave spectrum may reveal new information about the properties of the Martian surface.

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