atmosphere scans were obtained with the ultraviolet airglow spectrometer in the near-encounter sequence, and a series of drifts across the limb were obtained later, interleaved with television observations. The Venus encounter sequence was conducted as planned out to $E_V + 4$ days, when the television hourly cyclics were reduced to a 1-hour observing period every 8 hours, which continued until $E_V + 8$ days. It had been planned to monitor the ultraviolet markings until $E_V + 17$ days.

The high-gain antenna steering sequence discussed above was conducted during the earth occultation period. Analysis of preliminary data indicates that this technique was successful, yielding several kilometers additional penetration into the neutral atmosphere.

A number of spacecraft problems were encountered during the Mariner 10 mission. Of these, two affected the Venus encounter sequence significantly. First, the television optic heaters failed to come on shortly after launch. Thus, television instrument power had to be left on after the earth-moon calibration sequence to maintain optics temperatures within survival limits. The problem was cleared some 2 weeks before Venus encounter, but the 2 months of unplanned operation resulted in early termination of the postencounter television observations because of concern over instrument lifetime. Second, a roll gyro oscillation, which first occurred on 28 January, resulted in the cancellation of the roll calibration maneuver schedule for 12 February as a part of the Venus encounter sequence. Roll calibration maneuvers provide data which allow the determination of magnetometers zero offsets.

The roll gyro oscillation problem also resulted in the cancellation of trajectory correction maneuvers scheduled for 9 February and 1 March. A "sun-line" maneuver, that is, one in which no spacecraft attitude maneuvers are required, will be conducted in place of these maneuvers about 16 March. This change in maneuver strategy is not expected to degrade Mercury science because the mission-design aimpoint (a point which lies in both the sun and earth occultation zones at a periapsis altitude of approximately 1000 km) is still accessible. Mercury encounter will occur on 29 March between 2030 and 2100 G.M.T.

The Mariner 10 Venus encounter yielded a wealth of new information regarding the planet's atmosphere, figure, and solar wind interaction, extending and complementing results obtained by previous Mariner and Venera spacecraft. In addition to this general expansion of our knowledge, the Mariner 10 results should significantly benefit future missions to Venus. For example, the extraordinary and totally unexpected (by me at least) richness in structural detail observed in the upper atmosphere by near-ultraviolet imaging must be taken into account in selecting a strategy for remote sensing and in situ sampling of the Venus atmosphere. Similarly, the observation of apparent structureless homogeneity of the visible clouds and the existence of well-defined haze layers at their upper boundary is significant with regard to both models of the atmosphere and plans to probe it further.

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4 March 1974

Preliminary Infrared Radiometry of Venus from Mariner 10

Abstract. *The intensity of emission at 45 micrometers, measured with high spatial resolution along a single crossing of the Venus disk, is presented. On the average, the observed darkening toward the limb varies nearly linearly with the cosine of the emission angle. The brightness temperature, extrapolated to normal emission, is 255°K. The limb darkening curve, interpreted in a linear approximation, implies that the atmosphere is quite opaque, with an absorption coefficient of 0.24 per kilometer. Changes in curvature present in the limb darkening curve suggest the existence of thermal inhomogeneities with scale comparable to that of the dark markings shown by ultraviolet images.*

The infrared radiometer carried on Mariner 10 was designed specifically to make measurements of Mercury. However, the flyby of Venus provided an opportunity to observe the emission from the atmosphere of Venus at a wavelength inaccessible from the earth and with a spatial resolution exceeding the best obtainable at shorter infrared wavelengths from the earth.

The radiometer is essentially the same as that flown on Mariners 6, 7, and 9 (*1*), but with modifications as necessary to accept radiation in the 8- to 14-μm and in the 35- to 55-μm wavelength intervals. The radiometer was fixed relative to the spacecraft such as to give two traversals of Mercury; the orientation of the spacecraft relative to Venus resulted in only the single swath shown in Fig. 1. At 45 μm, the radiometer's field of view subtended an angle of 1.1°, giving a maximum linear resolution of about 200 km on the planet. The dynamic range of the 11-μm channel was adjusted for observations of the lighted surface of Mercury with an expected temperature of about 700°K. As a result, these shorter wavelength measurements of Venus provided only small signals and will not be discussed further. In contrast, the 45-μm channel was designed specifically for dark-side observations of Mercury, with a dynamic range up to 320°K.

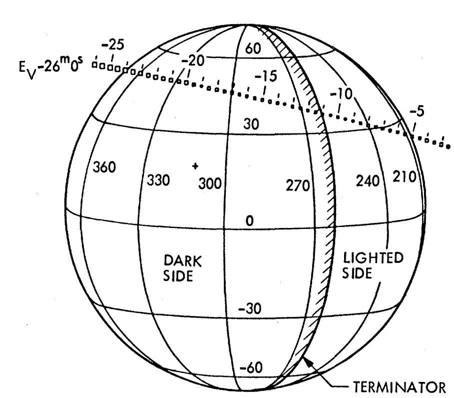

Fig. 1 Swath of the radiometer's field of view across the disk of Venus. The times indicated by the trace are given in minutes before the closest approach of Mariner 10.

The intensity of 45-μm radiation, $I_{45}(\mu)$, is shown in Fig. 2 as a function of the planetocentric longitude together with the deviation from a limb darkening law of the form

$$I_{45}(\mu) = I_{45}(1.0)\ (0.76 + 0.24\,\mu) \tag{1}$$

where μ is the cosine of the emission angle and I_{45} (1.0) is the intensity when $\mu = 1$. Because the data have not been corrected for out-of-field stray radiation and the trajectory geometry is still preliminary, only emission angles less than 65° have been included in obtaining the fit shown. The data can be represented equally well with a darkening law of the form

$$I_{45}(\mu) = I_{45}(1.0)\mu^{0.16} \qquad (2)$$

If the limb darkening shown in Fig. 2 is extrapolated to zero emission angle, the brightness temperature for normal emission is 255° ± 4°K. The calibration is preliminary, and as such uncertain; the errors quoted are statistical. If the thermal emission is assumed isotropic with a linear limb darkening of the form of Eq. 1, an integrated brightness temperature of 245°K is obtained. This is significantly below the value of 260°K obtained by Armstrong, Harper, and Low (*2*) for the planet as a whole over the wavelength passband from 30 to 45 μm, and may reflect either a dependence of darkening on latitude or a difference in the absolute calibrations.

The existence of a pronounced darkening toward the limb in 45-μm radiation can be interpreted in terms of the existence of a temperature gradient, with respect to optical depth, across the layers where this radiation originates. The actual value of the lapse rate at these levels is almost adiabatic (9°K/km), according to the results of the occultation experiment on Mariner 5 (*3*). On the assumption that the source of opacity at a wavelength λ is well mixed, the absorption coefficient per unit length, κ_λ, is easily derived by a linearized scheme. To the extent that the darkening toward the limb is linear in the cosine of the emission angle with a coefficient D_λ (see Eq. 1) the source function B_λ for thermal emission is linear with optical depth. If scattering is negligible, B_λ is Planckian, and from the formal integral of the equation of radiative transfer it is readily found that

$$\kappa_\lambda = \left[\frac{1}{B_\lambda}\frac{\partial B_\lambda}{\partial T}\frac{dT}{dz}\right]_{T=T_0} \frac{(1-D_\lambda)}{D_\lambda} \qquad (3)$$

where the term in brackets is evaluated at a "boundary temperature" T_0 defined by

$$B_\lambda(T_0) = I_\lambda(1.0)\,(1-D_\lambda) \qquad (4)$$

For the extrapolated normal brightness temperature at 45 μm, $T_B = 255°$K, and a darkening coefficient 0.24, Eqs. 3 and 4 give $T_0 = 222°$K and $\kappa_{45} = 0.24$ km^{-1}. Unit optical depth then corresponds to a difference in height of 4.1 km, a value which shows that the atmosphere of Venus is very opaque at 45 μm. It is of interest to compare this

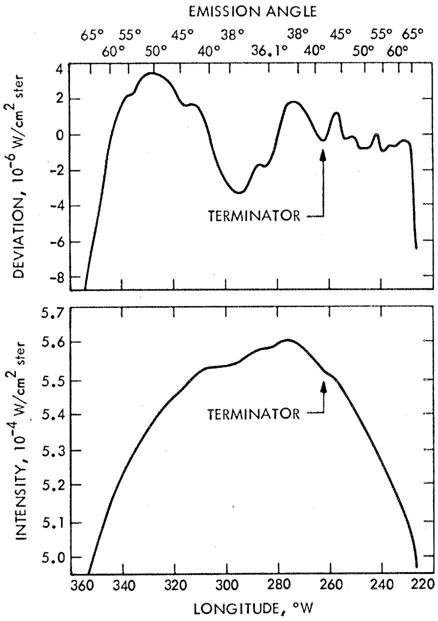

Fig. 2. (Bottom) The 45-μm intensity observed in the single swath across the disk of Venus is shown as a function of longitude. The pass went from the dark limb, at higher longitudes, and crossed onto the lighted side. (Top) The deviation from the linear limb darkening law described in the text is shown as a function of longitude. The limb darkening was derived from all data with emission angles less than 65°.

estimate of the opacity of the atmosphere of Venus at 45 μm with that obtained from Earth-based measurements in the 8- to 13-μm range. Detailed studies of the limb darkening of Venus in this range have been made by Pollack and Sagan (*4*), Goody (*5*), and Samuelson (*6*). The limb darkening function in the 10-μm range may, as discussed by these authors, be determined by scattering in addition to absorption effects. If the scattering-free approximation followed above for 45 μm is applied to the 10-μm Earth-based observations of Westphal (*7*), one obtains $T_0 = 204°$K and $\kappa_{10} = 0.26$ km^{-1}, for adopted values $T_B = 235°$K and $D_{10} = 0.54$. This would mean that the transparency of the atmosphere at 10 μm is comparable to that at 45 μm, and the "boundary temperatures" also should be comparable, in disagreement with observations. The discrepancy may be due to the erroneous assumption of negligible scattering made above.

Inferences about the source function or the opacity of an atmosphere, from limb darkening measurements at a single wavelength, can be made only for an atmosphere that is both thermally and optically homogeneous. Although the 45-μm measurements of Venus, in a mean sense, can be fit well by a linear darkening law, they do provide indications of inhomogeneities. The limb darkening measured when coming onto Venus appears steeper than that corresponding to the outbound phase, which contains the terminator. It cannot be ascertained, on the basis of these measurements, whether this is an effect of the insolation or a consequence of a latitude dependence of the temperature profile. In addition, the existence of thermal inhomogeneities in the atmosphere, not primarily due to insolation or latitude stratification, is revealed by the inflection points shown by the intensity curve of Fig. 2. Their angular scale (1/5 to 1/10 of the apparent disk) is comparable to that of the large markings apparent in television pictures of the planet taken through an ultraviolet filter. Because these features were measured beyond the terminator, however, it has not been possible to establish with certainty a correspondence with cloud features visible in television pictures. If the period of rotation is assumed to be 4 days, pictures taken 2 days after the infrared observations show a polar plume near the planetocentric location of the 45-μm features. This plume has a scale larger than that of the infrared features. A study of the correspondence between ultraviolet cloud patterns and the infrared radiation field should be an important subject for investigation in future missions.

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