References and Notes

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22. We acknowledge the ingenuity, diligence, and dedication of the many engineers and scientists of the Jet Propulsion Laboratory who have contributed to the Mariner 10 television experiment. In particular the skilled staff of the Space Photography Section, the Image Processing Laboratory, the Mission Test Computer, and the Mission Test Information System have played a major role in our work. James Anderson and Michael Malin of the California Institute of Technology, Robert Krauss of the University of Wisconsin, and Ken Klaasen and Robert Toombs of the Jet Propulsion Laboratory made major contributions. It has been a special privilege to work with Gene Giberson, manager of the Mariner-Venus-Mercury Project, and his able staff. Andrew Ingersoll of the California Institute of Technology supplied valuable criticism. Contribution No. 2458 of the Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91109. Research sponsored in part by NASA contract NAS 7-100. Kitt Peak National Observatory is operated by AURA, Inc., under contract to the National Science Foundation.

4 March 1974 ■

Ultraviolet Observations of Venus from Mariner 10: Preliminary Results

Abstract. *An objective grating spectrometer on Mariner 10 has measured airglow in the wavelength range 200 to 1700 angstroms. The data reveal the presence of significant concentrations of hydrogen, helium, carbon, and oxygen atoms in the upper atmosphere of Venus. A preliminary analysis of the hydrogen data indicates an exospheric temperature of 400°K. There is evidence for intense airglow emission at wavelengths longward of 1350 angstroms; the nature of this emission is unclear, but the radiation is spatially extensive and detectable on both day and night sides of the planet.*

The Mariner 10 payload included an objective grating spectrometer designed to measure airglow radiations from Venus and Mercury in the spectral range 200 to 1700 Å. A set of channel electron multipliers was used to detect radiation at ten selected wavelengths, with a spectral resolution of 20 Å. In addition, the spectrometer incorporated a pair of zero-order channels with effective band passes of 200 to 1500 and 1150 to 1700 Å, respectively. A summary of the various wavelengths, including information on possible radiating species, is given in Table 1. A more detailed description of the experiment will be presented elsewhere (*1*).

The spectrometer was mounted on the spacecraft scan platform, behind a sun shade. Observations were carried out in two modes, illustrated schematically in Fig. 1. In the first mode, the scan platform was placed in a fixed position and the spacecraft motion and limit cycle provided the desired change in the instrumental field of view (Fig. 1a). In the second mode, the clock coordinate (*2*) was fixed at a value corresponding to the center of the planetary disk, while the scan platform was moved in cone such that the field of view passed through successive levels of the atmosphere (Fig. 1b). The instrument has a field of view which measures 3° by ⅛°, with the larger dimension associated with the clock direction.

Observations were carried out in the fixed platform mode during the period 6 hours to 30 minutes before Venus encounter. The orientation of the slit, projected on the planet, is shown in Fig. 1a. The data obtained from the 1216 Å, 584 Å, and zero-order channels are given in Fig. 2. There is a perceptible rise in the Lyman alpha (1216 Å) channel prior to dark limb passage, indicating the presence of an extensive atmosphere of atomic hydrogen around Venus. There is evidence also for helium emission on the dark side of the planet, as may be inferred from the 584-Å record in Fig. 2. One would expect that the counting rate associated with sky background at 584 Å should vanish after dark limb passage. However, the counting rate in the 584-Å channel remained finite, and climbed rapidly as the field of view approached the bright limb. Extensive emission is evident also in the longer wavelength zero-order channel, Z02. The intensity of this radiation exceeds the sum of the intensities measured in all of the high-resolution channels. The nature of the emission and its mode of excitation remain unclear but should be clarified by a more extensive analysis of the data.

Observations of the bright limb were carried out from 9 minutes to 14 minutes after encounter, using the fixed platform observing mode. Strong emissions were detected at 584, 1048, 1216, 1304, 1480, and 1657 Å, and the variation of these emissions was measured as a function of altitude, as the field of view passed through successively higher atmospheric layers. Analysis of these data should eventually provide information on atmospheric temperature and will allow a careful study of the physical and chemical processes that regulate conditions in Venus's upper atmosphere. We are unable, however, to report on these matters at this time: Necessary pointing information and trajectory data were unavailable when this report was prepared.

A series of observations of the hydrogen corona were performed using the scanning mode at approximately 3 and 6 hours after encounter. The initial sequence consisted of four spatial scans, across the disk and off the limb to an altitude of 25,000 km. The scan sequence is shown schematically in Fig. 1b. The field of view of the spectrometer, projected on the planet, had a spatial extent of 230 km in the direction of the scan. The data from the four scans at 3 hours, superimposed to improve the statistics, are shown in Fig. 3. Figure 3 also includes, for comparison, Lyman alpha observations of

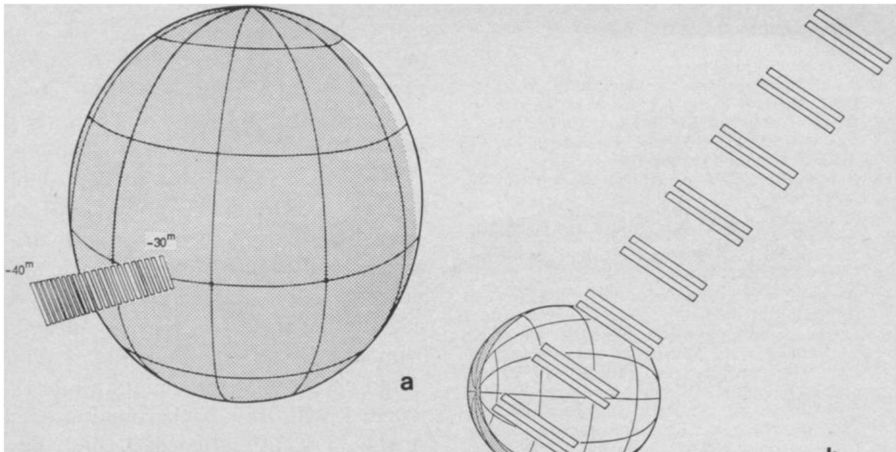
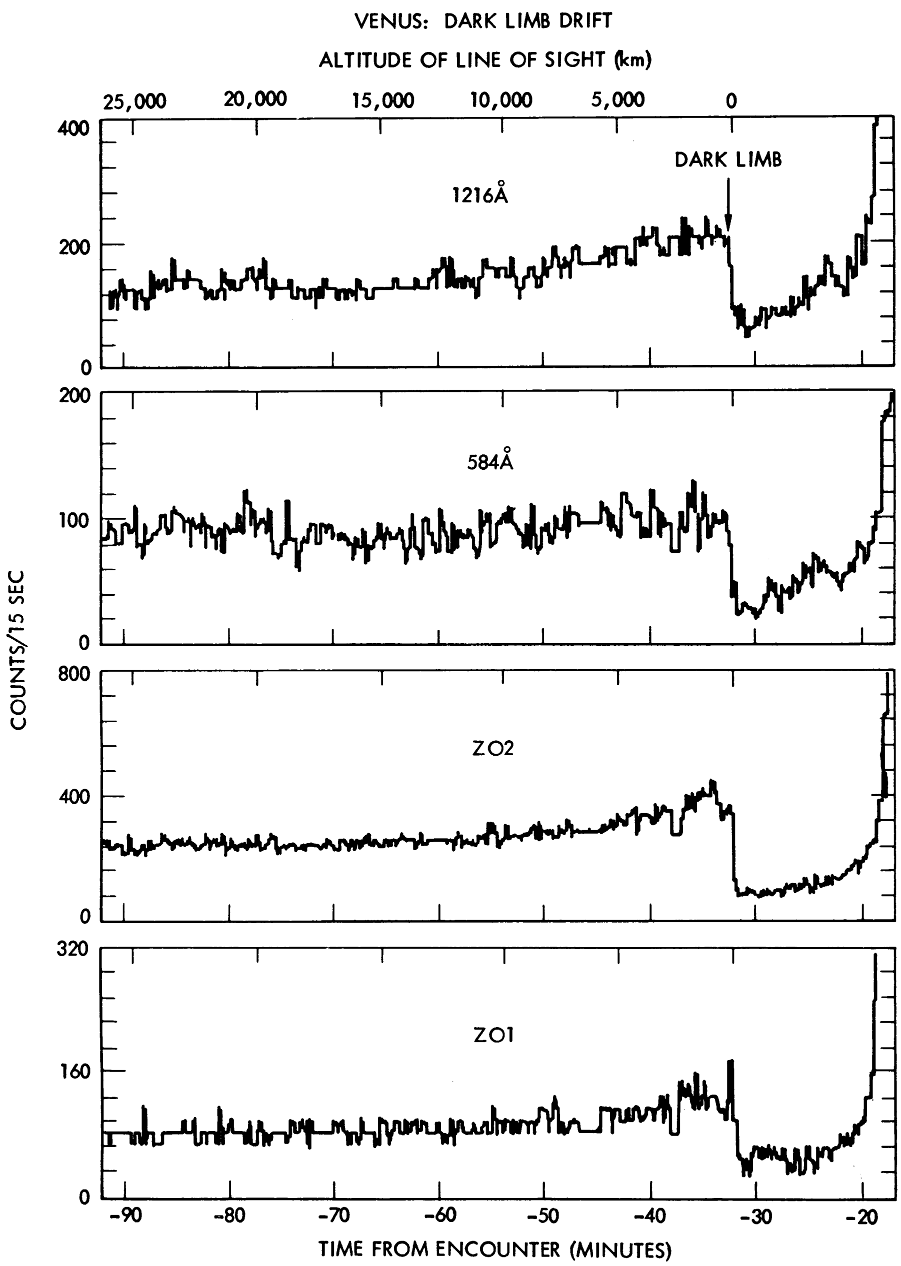


Fig. 1. (a) The dark limb drift experiment. The spectrometer slit positions relative to Venus are indicated at every 21 seconds. (b) The hydrogen scan experiment. The spectrometer slit positions at different times indicate the spatial extent of the scan relative to the planet.



Venus obtained by Mariner 5 (*3*). The Mariner 5 data were reduced by a factor of 4 to facilitate direct comparison with the present results and, in particular, to demonstrate the compatibility of the emission scale heights observed on both missions over the height range 1000 to 3000 km. The Mariner 5 data are also shown reduced by a factor of 0.7 to allow for a postflight recalibration of the earlier experiment (*4*).

It is difficult to escape the conclusion that the intensity of Lyman alpha was higher during the Mariner 5 encounter, by at least a factor of 2, over the height range 1000 to 3000 km. The discrepancy can scarcely be attributed to inconsistencies in the calibration procedures followed in the separate experiments. Sky brightnesses measured by the present experiment are consistent with data reported by Bertaux and Blamont (*5*) and by Thomas and Krassa (*6*). Their results imply that the background sky brightness observed by Mariner 10 during the scan sequence included in Fig. 3 should change by less than 15 rayleighs (*7*) between 16,000 and 30,000 km. The sky brightness measured by Mariner 5 is larger than the Mariner 10 value by no more than 50 percent. It would appear that the density of exospheric atoms responsible for scattering Lyman alpha, either hydrogen or deuterium, must be variable and that values which applied at any particular exospheric level during the Mariner 5 experiment must have exceeded values present during the Mariner 10 experiment by at least a factor of 2. We may note that the Mariner 10 flyby occurred during a period of relatively quiet solar conditions: The 10-cm solar flux measured at the earth during the Mariner 10 flyby had a value of 75×10^{-22} watt m^{-2} hertz^{-1}, compared with a value of about 120×10^{-22} watt m^{-2} hertz^{-1} which applied during Mariner 5.

Analyses of Mariner 5 data indicated that the Lyman alpha emission exhibited two separate scale heights, differing by an approximate factor of 2, and various interpretations (*8*) have been proposed to account for this phenomenon. The present observations show no indication of the extensive

Fig. 2. The data obtained at 1216 Å, 584 Å, and from the two zero-order channels are plotted against time from Venus encounter. These data were obtained during the dark limb drift experiment.

component observed by Mariner 5. It cannot be excluded, however, on the basis of the preliminary analysis reported here.

If we attribute the observed emission to resonance scattering by atomic hydrogen and use the exospheric theory presented by Chamberlain (*9*), we estimate an exospheric temperature of approximately 400°K. The Jeans escape rate for atomic hydrogen at this temperature would be about 10^4 atoms per square centimeter per second, some four orders of magnitude less than escape rates observed for the earth (*10*) and Mars (*11*).

The Mariner 10 observations provide the first positive detection of helium in the Venus atmosphere. The observed intensity at 584 Å is approximately 600 rayleighs, and both the intensity and altitude variations of the emission indicate that the atmosphere must be optically thick in the helium resonance line. The emission is most probably excited by resonance scattering of incident sunlight, and we estimate that the density of neutral helium at the critical level ($\sim$ 200 km) should be of the order of 10^5 cm^{-3}. Thermal escape of helium would be negligibly slow for Venus at an exospheric temperature of 400°K: Escape may proceed, however, by a variety of nonthermal processes, including capture by solar wind.

Mariner 10 also detected bright emission from atomic oxygens at 1304 Å, and from atomic carbon at 1657 Å. The intensity at 1304 Å is similar to that observed for the earth and larger by more than an order of magnitude than values reported for Mars (*12*). The present result is greater, by about a factor of 3, than 1304 Å intensities deduced by Moos and Rottman (*13*) from a rocket observation of Venus. The intensity at 1657 Å is more than an order of magnitude larger than an intensity computed by McElroy and McConnell (*14*) from a consideration of the possible photochemical sources of carbon. The computations, however, assumed an exceedingly low concentration for CO in the Venus thermosphere, and it would appear that the magnitude of the discrepancy could be reduced appreciably if CO were a major constituent of the upper atmosphere.

Table 1 shows a comparison of results obtained for Venus and the earth under similar observing conditions. Most notable are the exceedingly high count rates recorded for Venus in the zero-order channels. A combination of the total signals recorded by the individual channels from 304 to 1657 Å fails by a large factor to account for the zero-order signal: The excess signal is brighter than Lyman alpha by at least an order of magnitude. A comparison of the two zero-order channels suggests that the emission probably emanates at wavelengths longward of 1350 Å. Its intensity must exceed 10^6 rayleighs and may be as large as 4×10^6 rayleighs. Possible candidates for the emission include the fourth positive and Cameron bands of CO, as discussed by Rottman and Moos (*15*), with a possible contribution due to resonance scattering of sunlight by NO^+. No simple theory, however, can account for the detailed behavior of the observed emission, which exhibits an exceedingly large scale height, comparable to that of Lyman alpha, and is

Table 1. Comparison of dayglow observed at Venus and the earth by Mariner 10. The data for the earth were obtained at 2130 G.M.T., 3 November 1973, at 282,000 km, with a cone angle of 85.3°. Data for Venus were obtained on 5 February 1974 at two distances; the conditions were: 194,600 km, 2315 G.M.T., cone angle 151.8°; and 13,000 km, 1710 G.M.T., cone angle 131.0°. The numbers in parentheses below give the approximate intensities, in units of 10^3 rayleighs, for the Venus observations at 13,000 km.

Probable emitting species	Channel (Å)	Count rate (sec^{-1})		
		Earth 282,000 km	Venus 194,600 km	Venus 13,000 km
Zero order	1150–1700	880	15,800	26,200 (4,000)
Zero order	200–1500	640	8,480	12,160
He^+	304	5	22	100
Background	430	4	15	67
He	584	100	187	233 (0.61)
Ne	740	7	21	87
A	867	17	31	100
A	1048	21	39	147
H	1216	350	506	693 (19)
O	1304	120	127	267 (17)
CO, fourth positive	1480	4	173	987 (55)
C	1657	$\sim$ 1	53	260 (30)

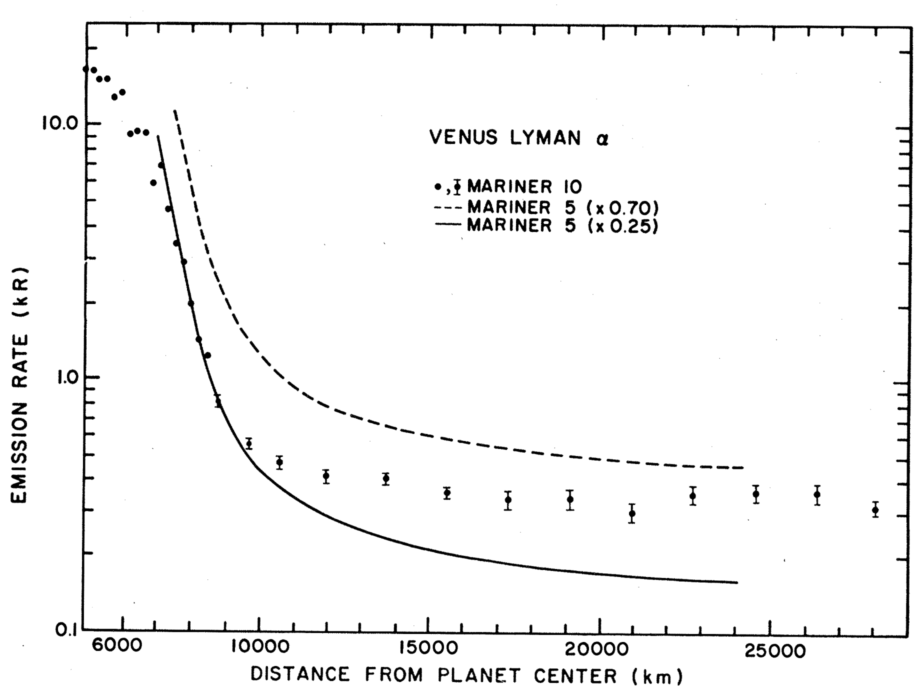


Fig. 3. Hydrogen Lyman alpha emission rate versus minimum distance of the line of sight from the center of the planet. For comparison, the data obtained by Mariner 5 scaled down by factors of 4 and 0.7 are also shown (see text).

readily detectable on both day and night sides of the planet. The high intensities measured at 1480 and 1657 Å, approximately 5.5×10^{10} and 3.0×10^{10} rayleighs, respectively, suggest that the emission may occur primarily at the longer wavelengths, and indeed this conclusion is apparently forced by a consideration of the available energy sources. The long-wavelength emission is one of the major surprises revealed by Mariner 10 and poses a considerable challenge in the continuing effort to unravel and interpret the ultraviolet results.

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2. The look direction is specified by the clock and cone angles. The cone, or polar, angle is measured with respect to the spacecraft-sun axis, with zero cone angle defining the solar direction. The clock, or azimuthal, angle is measured in a plane perpendicular to the spacecraft-sun axis, with its zero value defined by the projection of Canopus on this plane.
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6 March 1974

Search by Mariner 10 for Electrons and Protons Accelerated in Association with Venus

Abstract. *The University of Chicago instruments on board the Mariner 10 spacecraft bound for Mercury have measured energy spectra and fluxes of electrons from 0.18 to 30 million electron volts and protons from 0.5 to 68 million electron volts along the plasma wake and in the bow shock regions associated with Venus. Unusually quiet solar conditions and improved instrumentation made it possible to search for much lower fluxes of protons and electrons in similar energy regions as compared to earlier Mariner missions to Venus—that is, lower by a factor of 10^2 for protons and 10^3 for electrons. We found no evidence for electrons or protons either in the form of increases of intensity or energy spectral changes in the vicinity of the planet, nor any evidence of bursts of radiation in or near the observed bow shock where bursts of electrons might have been expected in analogy with the bow shock at the earth. The importance of these null results for determining the necessary and sufficient conditions for particle acceleration is discussed with respect to magnetometer evidence that Venus does not have a magnetosphere.*

The primary objectives for the University of Chicago charged-particle experiments on board the Mariner 10 spacecraft are to study the interactions of charged particle and magnetic field to distances within ~ 0.4 A.U. from the sun and to search for populations of charged particles that might be associated with the planet Mercury. However, since the trajectory for the

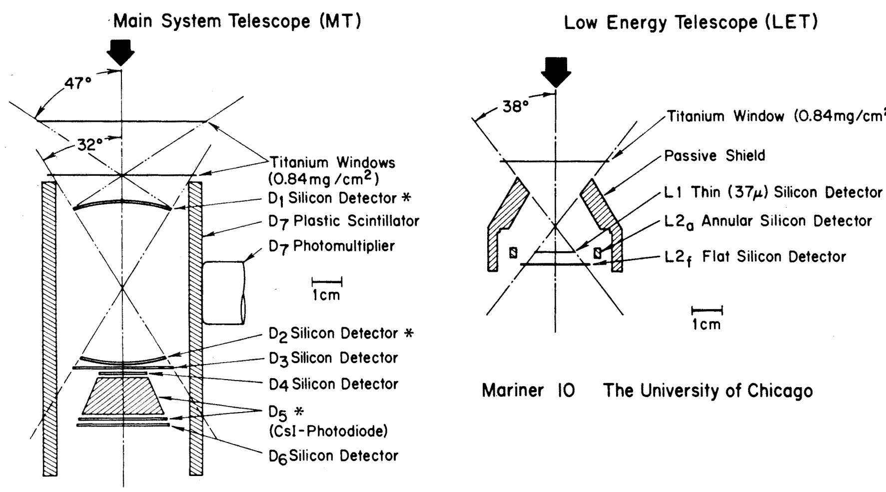

Fig. 1. Cross-section views of the sensing elements in the main telescope (MT) and the low energy telescope (LET) on Mariner 10 spacecraft. The main axis for the cones of particle acceptance for the MT and LET are 45° and 50°, respectively, with respect to the sun-spacecraft line, and ~ 15° out of the ecliptic plane. All detectors shown with asterisks have pulse-height analyzers. These telescopes and their electronics are almost identical with the Pioneer 10 MT (*9*) and LET (*9*).

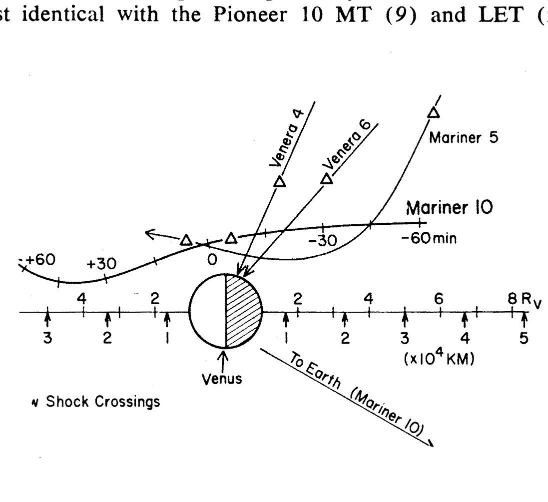

Fig. 2. Trajectories of spacecrafts are projected onto a polar coordinate plot. The trajectory for Mariner 2 in 1962 would lie outside the scale of this diagram. All bow shocks were identified by magnetometer observations as given in Table 1. The choice of trajectory for Mariner 10 was made to optimize the mission to Mercury (*13*).