properties of Earth's magnetosphere entitles one to derive a scaling law from Eq. 1, namely

$$R_V/R_E = 0.9\,(M_V/M_E)^{\frac{1}{3}} \qquad (2)$$

wherein R_V and R_E are the radial distances from the centers of Venus and Earth to corresponding points on their respective magnetospheric boundaries, and M_V and M_E are their respective magnetic dipole moments.

In Fig. 2 is a sketch of the magnetopause and shock front to be expected for M_V/M_E equal to 0.01, as scaled from the observed boundaries for Earth (*6*) with use of Eq. 2. Also shown is a portion of the encounter trajectory of Mariner V plotted in polar coordinates in the (rotating) plane which passes through Sun, the center of the planet, and the spacecraft. The interpretative use of such a plot includes the assumption of approximate axial symmetry about the Sun-planet line, as is established adequately for the present purpose by both theory and experiment. It is clear that Mariner V penetrated deeply into such a scaled magnetosphere.

Although the foregoing discussion is believed to be reliable in establishing a necessary condition for the existence of a radiation belt of durably trapped particles, it is less clear that such a condition is sufficient to assure the existence of a trapped particle population which would be detectable by our apparatus. We argue that it would be sufficient on the following grounds:

1) The magnetic and magneto-fluid dynamical conditions at the shock front and between the shock front and the magnetopause would be essentially identical with those of Earth's physical system.

2) The existence of easily observable patches or "spikes" of electrons ($E_e > 45$ kev) is characteristic of these regions around Earth (*7*) (as confirmed by the Mariner V apparatus) as well as of distances as great as 500,000 km "downstream" from Earth (*8*).

3) The frictional interaction between the solar wind and the magnetic field and ionized gas of the exosphere of Venus (*9*) would result in a system of polarization electric fields (or magnetic convection) that would accelerate particles and deliver them into the inner magnetosphere with an average increase of energy of some tens of kilovolts.

On these grounds we conclude that the absence of a detectable population of electrons ($E_e > 45$ kev) (Fig. 1) near Venus establishes M_V/M_E equal to 0.01 as a generous upper limit.

A diagram similar to Fig. 2 for M_V/M_E equal to 0.001 shows that the sunward magnetopause would then lie at the surface of the planet and that durable trapping of charged particles would be impossible. But, even in this case, shock-generated energetic electrons, or protons, or both, might be expected. No such "spikes" are evident in our data.

Nonetheless, both the magnetometer and the solar-wind detector (*3*) on Mariner V observed clear and significant, though weak, "signatures" of the planet. These effects have been attributed to the magneto-fluid dynamical interaction of the solar wind with the conducting ionosphere of the planet, the latter being clearly established by other experiments on Mariner V (*10*).

Since Venus has about the same size and average density as Earth and probably has a metallic core and an internal temperature similar to or greater than that of Earth (*11*) the very small (or perhaps zero) value of its intrinsic magnetic dipole moment is presumably attributable to its very slow rotation—a sidereal period of 245.1 ± 2 days (*12*) —and the consequent weakness of dynamo electromotive forces.

J. A. VAN ALLEN, S. M. KRIMGIS
L. A. FRANK, T. P. ARMSTRONG
Department of Physics and Astronomy, University of Iowa, Iowa City 52240

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11 December 1967

Ultraviolet Emissions Observed near Venus from Mariner V

Abstract. *A Lyman-alpha airglow of atomic hydrogen measured in the outer atmosphere of Venus showed that atomic hydrogen is present. The variation as a function of height indicates that the temperature of the upper atmosphere of Venus is lower than that of Earth. An ultraviolet airglow of atomic oxygen was not found. An ultraviolet nightglow was observed on the dark limb.*

The Mariner V flyby mission past Venus presented the opportunity to measure ultraviolet emissions from the upper atmosphere of Venus with a small instrument. The atmospheric species atomic hydrogen and atomic oxygen have resonance lines at 1216 and 1304 Å that may be measured with a simple ultraviolet photometer. The measurement of the ultraviolet emissions from resonance scattering of solar radiation by these atoms is a method of determining their density. The variation of the density as a function of height above the surface is a measure of the temperature of the outermost region of the atmosphere. Our experiment provides one part of a systematic study of the structure of the atmosphere of Venus. This is a report of the first preliminary results from the ultraviolet photometer experiment.

The ultraviolet photometer consists of three photomultiplier tubes, each with a different filter to isolate different regions of the vacuum ultraviolet spectrum. The photomultipliers, which have cesium iodide photocathodes and lithium fluoride windows, respond to ultraviolet radiation between 1050 and 2200 Å and have greatly decreased sensitivity at longer wavelengths. The three filters are the lithium fluoride window of the first tube and additional filters of calcium fluoride and barium fluoride for the other two tubes. The effective passbands for the three channels are:

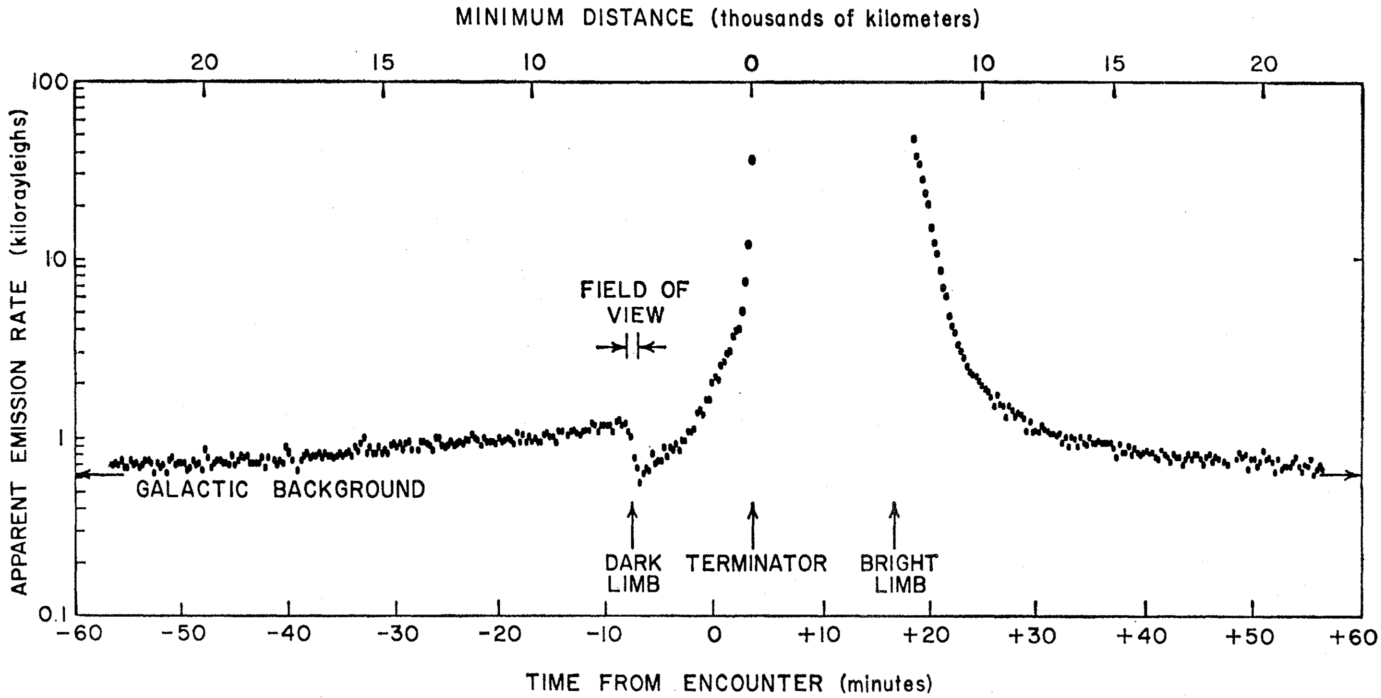

Fig. 1. Signal obtained from the lithium fluoride–Lyman alpha channel during the Venus encounter. Times when the photometer observed the dark limb, terminator, and bright limb are indicated. The minimum-distance scale gives the perpendicular distance from the photometer line of sight to the center of the planet.

1050 to 2200 Å, 1250 to 2200 Å, and 1350 to 2200 Å. The difference between the signals observed by the first two channels is due to the 1216-Å–Lyman alpha line of atomic hydrogen, and the difference between the second and third channels is due to the 1304-Å triplet of atomic oxygen. The third channel also measures any ultraviolet radiation at wavelengths greater than 1350 Å. The field of view of the lithium fluoride–Lyman alpha channel is 3.0°; the other two channels have fields of view of 1.2°. The three channels of the photometer are aligned and look in the same direction. The photomultiplier tubes operate with a variable high voltage controlled by the anode output current, so that each tube may operate with a dynamic range of 10^3 and may be protected from potential damage due to the brightness of the planet's sunlit disk. Similar photometers have been carried by some Aerobee rockets since 1963.

The ultraviolet photometer was mounted rigidly on the Mariner spacecraft, with its field of view perpendicular to the spacecraft-Sun line and pointed approximately toward the center of the planet at the time of closest approach. The instrument's field of view was approximately in the plane of the trajectory. Sun lay 32° above this plane. As the spacecraft approached the planet the instrument viewed the galactic background. Moving past Venus the photometer observed successively its outer atmosphere on the night side, the dark planet, the terminator, and finally the day side. The field of view then passed off the bright limb and measured the outer atmosphere which dropped of until only the galactic background was again observed. The arrows along the flight path indicate the viewing direction at the times of the dark-limb, terminator, and bright-limb crossings.

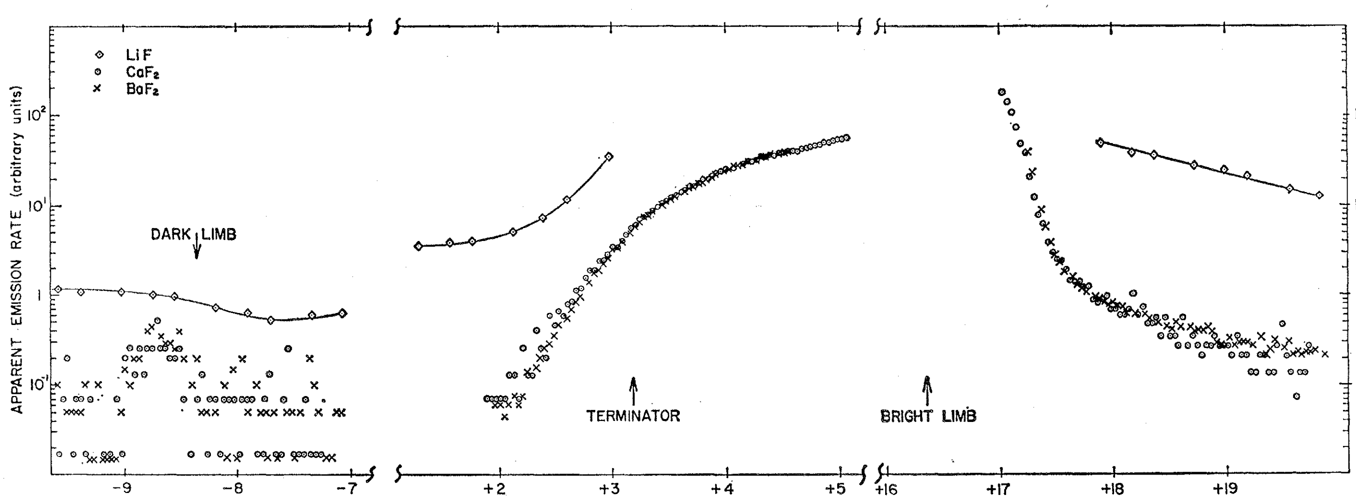

Fig. 2. Signals obtained from the three photometer channels during critical periods of the Venus encounter. Three expanded time intervals are shown: dark limb, terminator, and bright limb.

The measurements made by the lithium fluoride–Lyman alpha channel of the photometer from 60 minutes before until 60 minutes after encounter are shown in Fig. 1. The signals are given as apparent emission rates of the source in units of kilorayleighs (10^9 photons cm^{-2} sec^{-1}) for 1216 Å photons. The horizontal arrows on the left and right give the background measured 2½ hours before and 2½ hours after the encounter. This level is interpreted as principally due to atomic-hydrogen Lyman-alpha photons originating in the galaxy. When the spacecraft approached the planet the signal increased. This additional intensity was due to the presence of hydrogen atoms in the outer atmosphere of Venus that absorb solar Lyman-alpha photons, reradiate them, and produce an ultraviolet airglow. As the viewing direction of the photometer approached the dark side of the planet the Lyman-alpha signal reached a nightglow of several hundred rayleighs above the galactic background. When the field of view crossed the dark limb the ultraviolet signal from the galaxy was cut off by an absorbing gas or cloud layer. The intensity of the signal dropped by an amount equal to the galactic background signal. The sharp cutoff occurred during the time when the projected field of view moved past the absorbing edge of the planet (Fig. 1).

The spacecraft continued along its trajectory with the photometer looking at the night side of Venus. The Lyman-alpha signal increased as the field of view moved toward the terminator. This increasing signal intensity is a measurement of the Lyman-alpha twilight glow on Venus. The decreasing height of the shadow allowed progressively more hydrogen atoms to be illuminated by sunlight. As the field of view reached the terminator and the lower atmosphere became fully illuminated by sunlight, the lithium fluoride channel of the photometer read off-scale in response to ultraviolet daylight at longer wavelengths. Because of the long wavelength response, all three channels were adjusted to emphasize the terminator and bright-limb measurements and were allowed to go off-scale during the traversal of the bright disk.

The lithium fluoride–Lyman alpha channel remained off-scale as the field of view of the photometer moved across the daylight side of Venus. When the viewing direction passed off the bright limb, the lithium fluoride channel again measured Lyman-alpha radiation scattered by hydrogen atoms in the outer atmosphere of Venus. When the bright limb passed completely out of the field of view of the lithium fluoride channel, a strong signal was measured. The emission rate of the Lyman-alpha dayglow decreased rapidly as the viewing direction of the photometer moved away from Venus. The hydrogen atoms observed are in the upper atmosphere of the planet.

The observations of planetary Lyman-alpha radiation continued as the spacecraft moved in front of and away from the planet. The Lyman-alpha signal decreased until it again approached the intensity of the galactic background (the right edge of Fig. 1).

Measurements of all three channels of the photometer for particular phases of the encounter are shown in Fig. 2. The signals from the lithium fluoride, calcium fluoride, and barium fluoride channels are plotted (in arbitrary units) against the time (in minutes) from encounter. Compared with Fig. 1, the time scale is greatly expanded. Measurements from 9½ to 7 minutes before encounter at the time of the dark-limb crossing are shown on the left third of Fig. 2. Measurements by the lithium fluoride channel (the same as those in Fig. 1) show the position of the crossing of the absorbing edge of the planet at the time when the galactic signal dropped to half its value. Immediately before the dark-limb crossing, both the calcium fluoride and barium fluoride channels measured an increase in signal followed by a decrease. These measurements were interpreted as a night airglow that was enhanced because of the instrument's looking through the layer edge-on. The airglow layer was narrower than the projected field of view of the instrument, since the width of the maximum (Fig. 2) was equal to the time required for the field of view to pass over a narrow source. Both the calcium fluoride and barium fluoride channels measured the same variation in intensity, indicating that the wavelength of this airglow must be longer than 1350 Å. Data obtained from +1 to +5 minutes after encounter are shown in the middle part of Fig. 2, including the time of terminator crossing. The relative intensities of the signals from the calcium fluoride and barium fluoride channels have been adjusted to apply to an equivalent wavelength of 2200 Å. These two channels substantially track each other in the twilight and daylight observations on both sides of the terminator. These data suggest that the two channels measured the ultraviolet daylight, possibly the result of Rayleigh and particle scattering in the lower atmosphere of Venus. Perhaps the calcium fluoride channel also measured a weak airglow emission before it reached the terminator. The lithium fluoride channel, which had been measuring only Lyman-alpha radiation, increased rapidly when it approached the terminator because of the contribution of longer-wavelength ultraviolet daylight to its signal. The calcium fluoride and barium fluoride channels were both off-scale after they crossed the terminator.

Data obtained between +16 and +20 minutes after encounter, including the bright-limb crossing, are shown in the right third of Fig. 2. The calcium fluoride and barium fluoride channels again had their relative intensities adjusted for an equivalent 2200 Å signal. The signals from these two channels coincided when they were again on scale, as a result of the ultraviolet daylight at the edge of the planet which gradually moved out of the field of view. The lithium fluoride channel remained off-scale for almost 1 minute longer than the other two channels owing to its greater sensitivity and larger field of view; but, when it came back on, the signal that it measured was due principally to Lyman-alpha radiation.

Results from the lithium fluoride–Lyman alpha channel show that the amount of atomic hydrogen in the upper atmosphere of Venus is comparable to the amount in the upper atmosphere of Earth. The atomic hydrogen atmosphere of Venus is much less extended than that of Earth. This implies that the temperature in the upper atmosphere of Venus several hundred kilometers above the surface is low, much lower than the temperature at comparable heights in Earth's atmosphere. The lower temperature means that the escape rate of atomic hydrogen from Venus is much lower than it is for Earth.

The signals obtained from the calcium fluoride and barium fluoride channels just beyond the bright-limb crossing show no evidence of atomic oxygen emission. These signals are consistent with the low temperature as measured by atomic hydrogen density.

On the night side of Venus there is a weak ultraviolet airglow above the ultraviolet-absorbing atmosphere. This emission may result from chemical reactions between atmospheric species previously photodissociated or from charged-particle bombardment.

CHARLES A. BARTH
JEFFREY B. PEARCE
KENNETH K. KELLY
Department of Astro-Geophysics and Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder 80302
LLOYD WALLACE
Kitt Peak National Observatory, Tucson, Arizona 85717
WILLIAM G. FASTIE
Department of Physics, Johns Hopkins University, Baltimore, Maryland 21218

Notes

1. Preparations for the experiment were begun in early 1963. The instruments were built by Labko Scientific, Inc., Stillwater, Oklahoma, under the direction of L. C. Labarthe. The integration of the instruments onto the spacecraft was conducted by G. McNutt and E. F. Mackey of Packard Bell Electronics, Newbury Park, California; and E. McMillan, H. Canvel, A. Lane, and R. Carlson of the Jet Propulsion Laboratory. The data reduction was carried out by Mrs. C. Leyner, Mrs. S. Schaffner, and D. E. Anderson of the University of Colorado, with the help of the University Computing Center. During the early stages of the formulation of the experiment, J. W. Chamberlain and J. C. Brandt of Kitt Peak National Observatory, Tucson, Arizona, contributed useful ideas.
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Venus: Ionosphere and Atmosphere as Measured by Dual-Frequency Radio Occultation of Mariner V

Abstract. *Venus has daytime and nighttime ionospheres at the positions probed by radio occultation. The main layers are thin by terrestrial standards, with the nighttime peak concentration of electrons being about two orders of magnitude below that of the daytime peak. Above the nighttime peak were several scale-height regimes extending to a radius of at least 7500, and probably to 9700, kilometers from the center of Venus. Helium and hydrogen at plasma temperatures of 600° to 1100°K seem indicated in the regimes from 6300 to 7500 kilometers, with cooler molecular ions in lower regions. Above the daytime peak a sharp plasmapause was discovered, marking a sudden transition from appreciable ionization concentrations near Venus to the tenuous conditions of the solar wind. This may be indicative of a kind of interaction of the magnetized solar wind with a planetary body that differs from the two different kinds of interaction characterized by Earth and by Moon. For Venus and probably for Mars, the magnetic field of the solar wind may pile up in front of the conducting ionosphere, form an induced magnetosphere that ends at the plasmapause, above which any ionosphere that tends to form is swept away by the shocked solar wind that flows between the stand-off bow-shock and the magnetopause. The neutral atmosphere was also probed and a surface reflection may have been detected, but the data have not yet been studied in detail. Results are consistent with a super-refractive atmosphere, as expected from Soviet measurements near the surface. Thus, two unusual features of Venus can be described in terms of a light trap in the lower atmosphere, and a magnetic trap in the conducting ionosphere.*

As Mariner V passed behind Venus on 19 October 1967, dual-frequency radio transmissions from Earth reached the spacecraft after passing through Venus's ionosphere and atmosphere. Signal characteristics were measured and stored on magnetic tape for later transmission to Earth on the telemetry channel. From these characteristics, preliminary profiles of electron concentration as a function of radius have been derived, by techniques described previously (*1*), for both the nighttime and daytime ionospheres probed by the signals. Effects of the dense neutral atmosphere were measured over the same two regions on Venus, but very little analysis has been attempted thus far since the principal effects of the lower atmosphere were more accurately determined in the S-band experiment (*2*). During the cruise portion of the mission, the dual-frequency experiment measured characteristics of the interplanetary plasma, but these results will be reported elsewhere.

This is primarily a report on the planetary data obtained from the dual-frequency experiment, including some very preliminary discussion and interpretation relative to physical and chemical properties of the upper atmosphere. In addition, we discuss briefly how the results may help define a third type of interaction of a planetary body with the solar wind, where that of Earth and Moon represent the other two types.

Harmonic, continuous-wave signals at 49.8 and 423.3 Mhz were transmitted from a 150-foot (46-m) steerable, parabolic antenna at Stanford. Transmitter powers were about 350 kw at the lower, and 30 kw at the higher, frequency. The signals were received by fixed, low-gain antennas on the spacecraft provided by feeding two of the solar panels for the lower frequency, and by adding a dipole with reflectors at the end of one of the panels for the higher frequency. The design of a phase-locked, dual-frequency receiver for interplanetary plasma measurements on Pioneer spacecraft was modified for the Mariner instrument.

At the spacecraft, the 2/17th subharmonic of the higher frequency was compared with the lower frequency to provide a beat note whose frequency was measured by counting positive and negative zero crossings. These counts provided a dispersive Doppler measurement of the change in the amount of plasma along the path, with one count representing a change of about 2×10^{14} electrons m^{-2}. The sign of the change could also be determined since the two frequencies actually differed from the 2/17 ratio by a precisely determined bias of 50 hz. Thus the count was 60 in the 0.6-second sampling period if no change of ionization occurred along the changing path in that interval of time, and values larger or smaller than 60 indicate the amount and sign of the change.

The amplitudes of each of the two signals were measured every 0.6 second during encounter. Changes in amplitude caused by Venus were expected due to: (i) focusing and defocusing in its ionosphere; (ii) defocusing in its neutral atmosphere; (iii) possible absorption in its ionosphere or atmosphere; and (iv) the possible diffractive cutoff of signals by the limb of the solid planet. It appears that (i) and (ii) were seen and (iv) was not seen, while it has not yet been determined whether or not there was any measurable absorption.

The dispersive Doppler and two sets of amplitude measurements constitute the results of the experiment to be discussed further. While the frequencies of the two signals were also measured, and several differential group-path measurements were made near encounter, they are not sufficiently pre-