Mariner II: Preliminary Reports on Measurements of Venus

The Mariner II spacecraft successfully completed its 109-day journey through interplanetary space and on 14 December 1962 passed Venus at a minimum distance of approach to the planet's center of 41,000 kilometers (6.6 radii of the solid body of the planet). The achievement permitted the first *in situ* scientific measurements in the vicinity of any planet other than Earth. The results of some of these measurements are reported in the papers that follow.

Charged Particles

Abstract. *There was a complete absence of charged particles associated with the planet Venus at radial distances as small as 41,000 km on the sunward side of the planet. This result is taken to mean that the magnetosphere of Venus, if any, does not extend to that great a distance. The most plausible interpretation is that* $(M_V/M_E) \lesssim 0.18$, *where* M_V *and* M_E *are the dipole magnetic moments of Venus and Earth, respectively. The results are consistent with* $M_V/M_E = 0$. *Certain qualifications prevent this interpretation from being a definitive one.*

This experiment was the pioneering attempt to search for charged particles magnetically trapped in the vicinity of the planet Venus and, if such particles were found, to obtain measurements of their spatial distribution and intensity. The equipment comprised a thin-window Geiger-Mueller tube which was included in the scientific payload of the Mariner II spacecraft of the Jet Propulsion Laboratory.

Table 1. Properties of the Iowa detector.

Detector: Anton type 213 Geiger-Mueller tube
Weight of detector assembly: 60 g
Window thickness: 1.2 mg cm^{-2} mica
Full angle of collimator: 90°
Directional geometric factor: 0.2 cm^2 sterad
Efficiency for electrons:
~ 1.0 for $E > 70$ kev
0.35 for $E = 40$ kev
0.1 for $E = 34$ kev
0.01 for $E = 29$ kev
10^{-3} for $E = 27$ kev
10^{-6} for $E = 5$ kev (nonpenetrating)
Efficiency for protons: ~ 1.0 for $E > 500$ kev
Side shielding: 0.35 g cm^{-2} of stainless steel and magnesium
Omnidirectional geometric factor: 0.2 cm^2
Maximum apparent counting rate: 50,000 count sec^{-1}
Maximum observable true counting rate by use of laboratory calibration curve: 10^7 count sec^{-1}

A description of the Iowa equipment and a preliminary account of the interplanetary observations during September and October 1962 have been published (*1*). The low-energy particle detector consisted of a collimated Anton type 213 Geiger-Mueller tube having a 1.2 mg cm^{-2} mica window (nominal range of 40 kev electrons or 500 kev protons). Throughout the flight, including the planetary fly-by, the axis of the detector's conical field of view (90° full angle) was directed at 70 ± 1° to the spacecraft-sun line, lay in the plane containing the sun, earth, and spacecraft, and was on the earthward side of the spacecraft.

A summary of detector characteristics is given in Table 1.

Observations. In the upper portion of Fig. 1 is plotted the true counting rate *R* of the detector as a function of Universal Time during the planetary "encounter" period as well as during periods of about 30 hours before and after the time of closest approach. Also shown on the same time scale are the Sun-Venus-probe angle L_{SVP} and the radial distance from the probe to the center of the planet R_V. During the interplanetary, or "cruise," mode of operation of the spacecraft, the accumulated number of counts from the detector during a 9.60-second interval was read out once each 887 seconds. During the "encounter mode" the accumulated number of counts during a 9.60-second interval was read out once each 484 seconds. Each plotted point in Fig. 1 represents a single sample and has, therefore, a statistical uncertainty of about 25 percent. Closest approach occurred at 20:00 UT on 14 December 1962, at a radial distance from the center of the planet of 41,000 km, at a Sun-Venus-probe angle of 71°, and at a Venus-referenced declination of −38°. The latter angle was measured from a plane through the center of Venus parallel to the plane of the ecliptic. The "encounter mode" of spacecraft operation was in effect from 13:35 UT to 20:40 UT on 14 December.

The most striking feature of Fig. 1 is the absence of any discernible increase in counting rate during passage by Venus.

This impression is made more quantitative by reference to Table 2 and to the following discussion. For the 50 samples obtained during the encounter mode, the observed root-mean-square deviation from the mean counting rate was 0.28 count sec^{-1}, and the statistically expected value σ was 0.33 count sec^{-1}.

Fifteen of the 50 sample rates differed from the mean rate 1.125 count sec^{-1} by an amount equal to or greater than σ, and none differed by as much as 2 σ. Of those which differed by as much as, or more than, σ, nine exceeded the mean and six were less than the mean. Both positive and negative deviations appeared to be randomly distributed through the period of the encounter mode.

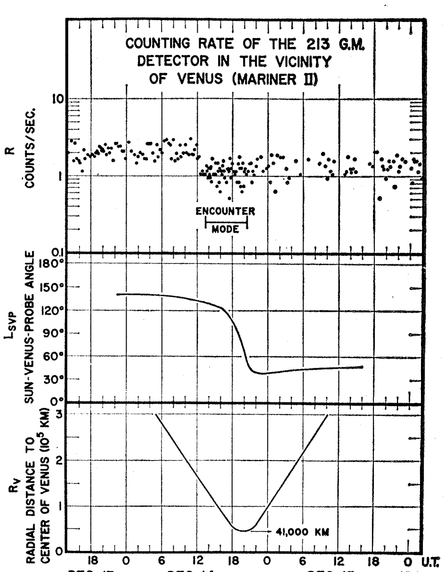

Fig. 1 Plot of the counting rate of the detector in the vicinity of Venus. Each plotted point represents the average counting rate over a time interval of 9.60 seconds. The two lower graphs show, on the same time scale, the time dependence of two coordinates of the trajectory of the spacecraft.

Thus it appears that the absence of a discernible effect in the vicinity of the planet was as complete as was possible on statistical grounds.

A somewhat broader view of the matter can be obtained from an examination of Fig. 1 and Table 2. The mean counting rate during the encounter mode was actually significantly less than that during either the prior period of flight or, to a lesser extent, the subsequent period. There are three conceivable explanations for this effect: (i) an instrumental effect peculiar to the encounter mode of spacecraft operation; (ii) an incidental decrease in the intensity of low-energy particles in interplanetary space, such decrease having no relationship to the proximity to the planet; (iii) a geometric or magnetic "shadowing" effect by the planet.

With the help of Hugh Anderson and several other persons at the Jet Propulsion Laboratory we have examined the first explanation by using the telemetered "engineering data" and other knowledge of the spacecraft's operation. No plausible foundation for this explanation has been found. Moreover, Fig. 1 and Table 2 show that the sharp drop in counting rate occurred at about 12:20 UT during the "cruise mode" and over an hour before the "encounter mode" was actuated. No discontinuity in counting rate occurred at either the beginning or the end of the "encounter mode." Hence we have rejected the first explanation.

In order to accept the third explanation, that the planet had a geometrical or magnetic "shadowing effect," some reasonable physical mechanism must be proposed. For example, one might expect a reduced intensity of particles in the solar wind within a region of finite dimensions on the leeward, or antisolar, side of a nonmagnetic planet. But the rapid reduction in the counting rate of our detector occurred at a position 164,000 km (26.4 planetary radii) from the center of the planet at a Sun-Venus-probe angle of 133° and a planet-referenced declination of +19°. At this time the detector's cone of acceptance was directed generally away from the planet. Thus, such a shadowing seems to be a most unlikely possibility, even if the planet were magnetic and had an effectively greater cross-section. Moreover, there was no evidence for a subsequent return of the counting rate to its "unshadowed" value.

For the reasons cited, we judge that only the second explanation—that is, that there was an incidental decrease in the intensity of low-energy particles in interplanetary space—is acceptable. It is a matter of some comfort that sharp changes in counting rate of similar magnitude were observed at several other times during the 2½ months of interplanetary flight under constant operating conditions at positions very remote from either Earth or Venus. The counting rate due to galactic cosmic rays alone was 0.6 sec^{-1}.

It may be noted here that at no time during the planetary fly-by did the planet fall within the conical field of view of the detector.

Significance of the observations. It may be presumed that the foregoing observations provide a foundation for determining an upper limit to the dipole magnetic moment of Venus. Our attempt to do so is in the form of a similitude argument, utilizing existing knowledge of the radiation environment of Earth.

A detector similar to that in Mariner II but with a smaller opening angle (30° full angle) and a much smaller geometric factor (2×10^{-3} cm^2 steradian) was flown in the earth satellite Explorer XIV out to radial distances of 16.5 earth radii. Figure 2 is reproduced from a report on that work (*2*). The curve marked 213A is the counting rate curve for the detector in question. It can be inferred from Fig. 2 that if the Iowa detector in Mariner II was placed at a radial distance of 41,000 km from the center of Earth

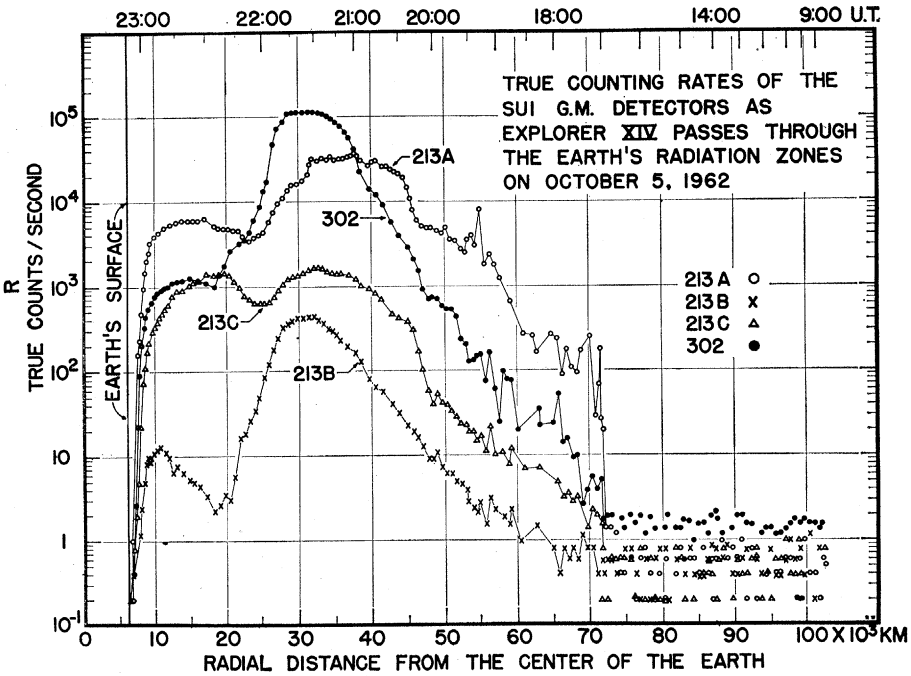

Fig. 2. A graph of experimental results from Explorer XIV on the radiation belts of Earth, after Frank *et al.* (*2*). These data form the basis of a similitude argument for determining an upper limit on the magnetic moment of Venus from the Mariner II observations shown in Fig. 1.

Table 2. Summary of count-rate data in the vicinity of Venus.

Time period (UT) (Dec. 1962)	Radial distance range (10^3km)	Mean counting rate and its statistical uncertainty (count sec^{-1})	Spacecraft mode
16:03/13 Dec. to 12:15/14 Dec.	569 to 167	2.097 ± 0.058	Cruise
12:33/14 Dec. to 13:14/14 Dec.	161 to 147	1.15 ± 0.17	Cruise
13:35/14 Dec. to 20:40/14 Dec.	140 to 41 to 45	1.125 ± 0.049	Encounter
20:55/14 Dec. to 03:07/15 Dec.	48 to 160	1.366 ± 0.086	Cruise
03:19/15 Dec. to 11:51/16 Dec.	163 to 809	1.329 ± 0.031	Cruise

in the magnetic equatorial plane with its axis orthogonal to the B vector, then its true rate would be of the order of 10^6 count sec^{-1}; and that even at 65,000 km it would be of the order of 10^4 count sec^{-1}. Thus, it is clear that the radiation environment of Venus is vastly different than that of Earth. However, the nonlinear character of the similitude argument is evident from the precipitous decline in trapped particle intensity at 72,000 km, shown in Fig. 2. If our Mariner II equipment had been flown past Earth at a minimum distance of approach of 75,000 km on the sunward side of the magnetosphere on 5 October 1962, then the results would have been as negative as were those from the Venus flyby on 14 December.

By means of Explorer XII (*3*) and Explorer XIV (*2*) it has been found that there is often a sharp outer boundary of the magnetosphere (such as exemplified by Fig. 2) as defined by the intensity of electrons of $E > 40$ kev and a nearly coincident discontinuity in the magnitude and direction of the magnetic field. The radial distance to this outer boundary is typically 8 to 11 earth radii. On some occasions, even on the sunward face of the magnetosphere, there is no sharp discontinuity and the intensity of low-energy, trapped electrons dwindles gradually with increasing distance to a radial distance as great as 14 or 15 earth radii.

For the purposes of an exemplary calculation, let it be assumed that the magnetic moment of Venus is perpendicular to the plane of the ecliptic, and that the solar wind which was impinging on the magnetosphere of Venus on 14 December was similar to that responsible for the termination of the magnetosphere of Earth on 5 October (Fig. 2) (the latter assumption is supported by auxiliary geomagnetic data for the two periods in question). If it is further assumed that the magnetospheric boundary occurs at a given value of planetary magnetic field, under given solar wind conditions, then the Mariner II results imply the following upper limit for the ratio of the magnetic moment of Venus M_V to that of Earth M_E.

$$\frac{M_V}{M_E} \leq \left(\frac{41,000}{72,500}\right)^3 = 0.18$$

We regard this estimate as reasonable but do not regard it as definitive. For example, if the magnetic moment of Venus was in the plane of Mariner II's trajectory and perpendicular to the trajectory at its point of closest approach the fly-by at 41,000 km would have just reached the dipole line of force which crosses the magnetic equator at 106,600 km. This line of force on the sunward side of the earth has never been observed to be populated by a detectable intensity of trapped particles of energy to which our Mariner II detector was sensitive. Hence, in this case M_V/M_E might be equal to or somewhat greater than unity.

It is probable that the heliocentric variation of the dynamic pressure of the solar wind between the orbit of Venus (0.72 astronomical unit) and the orbit of Earth (1.00 A.U.) is less than the day-to-day and week-to-week variations at Earth. Hence no attempt has been made to invoke this consideration, which is in effect buried among other uncertainties previously mentioned.

It may be remarked that our Mariner II detector, though having a wide angle (90°) collimator, was a directional one and was carried past Venus in an oriented vehicle. Since the angular distribution of magnetically trapped particles is always anisotropic, it is of importance to inquire whether the observed null result could have been a false one due simply to the fact that the detector had an unfavorable aspect during its passage through a field of radiation. We examined this possibility for various orientations of the planetary magnetic moment with the help of a model and concluded that such a result was exceedingly unlikely.

The results of the magnetometer observations made with Mariner II may contribute to the determination of an upper limit to M_V, but the interpretation of a null effect on a magnetometer is closely related to the interpretation of the absence of magnetically trapped, charged particles and it is doubtful that anything essentially different can be derived from the magnetic observations. It is assumed implicitly in our interpretation that the processes leading to the development of the radiation belts of Earth also occur in the magnetospheres of other magnetized planets and that the important processes scale in some continuous manner and not discontinuously with the magnitude of the magnetic moment of the planet in question.

In the spirit of the theory of planetary magnetism, our results are consistent with the radar astronomical evidence that the rotational period of Venus is approximately equal to its period of revolution about the sun (*4, 5*).

L. A. FRANK
J. A. VAN ALLEN
H. K. HILLS
Department of Physics and Astronomy, State University of Iowa, Iowa City

References and Notes

1. J. A. Van Allen and L. A. Frank, *Science* **138**, 1097 (1962).
2. L. A. Frank, J. A. Van Allen, W. A. Whelpley, J. D. Craven, *J. Geophys. Res.*, in press.
3. W. G. V. Rosser, B. J. O'Brien, J. A. Van Allen, L. A. Frank, C. D. Laughlin, *ibid.* **67**, 4533 (1962); J. W. Freeman, J. A. Van Allen, L. J. Cahill, *ibid.*, in press.
4. G. H. Pettengill, H. W. Briscoe, J. V. Evans, E. Gehrels, G. M. Hyde, L. G. Kraft, R. Price, W. B. Smith, *Astron. J.* **67**, 181 (1962); R. M. Goldstein and R. L. Carpenter, *Science*, this issue.
5. This work was supported in part by the Jet Propulsion Laboratory and by our NASA grant NsG-233-62. We are particularly indebted to Conway W. Snyder, Hugh R. Anderson, and Leonard G. Parker (J.P.L.) for essential assistance with many aspects of the work and to C. S. Wang (State University of Iowa) for assistance with data reduction. Two of us (L.A.F. and H.K.H.) are graduate research fellows of the National Aeronautics and Space Administration.

26 February 1963

Infrared Radiometer

The infrared radiometer which was flown on Mariner II in conjunction with the microwave radiometer was designed to measure, with high geographical resolution, the infrared radiation from Venus in two wavelength regions. One of these was centered on the 10.4-μ carbon dioxide band, while the other was selected to correspond to an infrared window centered at 8.4 μ.

The characteristics of the two-channel instrument, which was built by the Barnes Engineering Company, follow: weight, 2.88 lbs; power, 2.4 watts; field of view, 0.9 by 0.9 deg; integration time, 3 seconds between 10 and 90 percent points. The detectors were 0.15- by 15-mm thermistor bolometers immersed in germanium. Channel 1 operated in the spectral region 8.1 to 8.7 microns, channel 2 in the region 10.2 to 10.5 microns. The radiometer, designed to measure radiation temperatures between 200°K and 600°K, chopped the planetary radiation against dark space by means of a mirrored chopper operating at 20 cy/sec. Two essentially identical optical systems looking 45 deg apart were utilized.

The infrared radiometer was mounted