The Mission of Mariner II: Preliminary Observations

Profile of Events

The interplanetary spacecraft Mariner II, designed and built by the Jet Propulsion Laboratory of the California Institute of Technology, was launched from Cape Canaveral by an Atlas-Agena propulsion system at 06h 53m 14s Universal Time on 27 August 1962. In addition to two radiometers designed to make close-up measurements of the electromagnetic radiation from Venus in the microwave and infrared spectral regions, it carries seven other scientific instruments to observe various features of the interplanetary medium. Preliminary results of some of these experiments are discussed in the papers which follow.

Mariner II is, by a large margin, the most successful interplanetary space probe which has ever been sent out from the earth. It will pass closer to another planet than any of its predecessors. No other attitude-stabilized spacecraft has operated so far into space. Rocket propellants have never before been stored in space for so long and then used successfully. This is the deepest penetration into space at which a craft has been commanded and which, in response, performed maneuvers successfully. Far more data from translunar space have been recorded on earth from Mariner II than were ever received before—720,000 data bits per day for more than 75 days (as of 20 November 1962).

Some of the significant events in the voyage of Mariner II are listed below; the times are given in days after launch and the distances from the spacecraft to the earth in gigameters (1 Gm = 10^9 meters = 1 million kilometers = 621,370 miles).

1) 2.39 days, 0.72 Gm: The interplanetary experiments were begun.

2) 8.73 days, 2.41 Gm: The orbit was corrected in response to radio command from earth.

3) 38.73 days. 9.96 Gm: The spacecraft stopped falling behind the earth and began to overtake it (that is, earth and spacecraft had equal angular velocities about the sun).

4) 65.40 days, 19.10 Gm: The spacecraft passed the earth (that is, heliocentric longitude of earth and spacecraft were the same).

5) 65.57 days, 19.23 Gm: The interplanetary experiments were turned off by radio command from earth because of the malfunction of one of the solar power panels.

6) 73.61 days, 23.56 Gm: Interplanetary experiments turned on again by radio command from earth after solar power returned to normal.

7) 81.0 days, 28.5 Gm: New distance record was attained for the transmission of telemetry data, and surpassed that set by Pioneer V in June 1960. The Pioneer V record for one-way transmission of a radio signal (36.15 Gm) will have been surpassed at 90.18 days if Mariner II is still operating at that time.

8) 109.33 days, 57.70 Gm: Mariner II will pass by Venus at a distance of 0.04 Gm from the center of the planet.

Solar Plasma Experiment

Abstract. A preliminary summary of the data received from the Mariner II solar plasma experiment for the period 29 August through 31 October 1962 is presented. During this period there was always a measurable flow of plasma from the direction of the sun. The velocity of this ion motion was generally in the range 400 to 700 km/sec. Time variations, plasma density, and ion temperatures are also discussed.

The Mariner II solar plasma experiment is made with a single electrostatic spectrometer which always points to within less than ½ degree of the center of the sun. Positively charged particles of kinetic energy per unit charge, E/Q, within a certain range, and of near-normal incidence are allowed to pass through the spectrometer to a Faraday cup. The current to this cup is measured for each of ten ranges of E/Q, 3.7 minutes being required to obtain a complete spectrum.

Data were received from the interplanetary experiments on Mariner II almost continuously from 29 August through 31 October 1962. In this period, approximately 23,550 spectra were received from the plasma experiment; of these, approximately 20,200 have already been made available for analysis.

One of the principal results of the Mariner plasma experiment is the finding that there was always a measurable flow of plasma from the direction of the sun. The data are summarized in Fig. 1, which contains eight plots of the logarithm of the collected current versus time—one plot for each value of E/Q between 516 and 8224 volts. Each bar represents the total spread in measured current for the time corresponding to 256 spectra, or 15.77 hours.

The lines in Fig. 1 marked 130 and 140 correspond to approximately 10^{-11} and 10^{-12} ampere, respectively; thus, the vertical distance between these lines is equivalent to one decade of collected current. The largest current observed during the 63-day period was about 4×10^{-10} ampere. Measurements were also made at values of $E/Q = 231$ and 346 volts; however, the currents in these ranges of E/Q are not plotted because they were always below 10^{-13} ampere.

From Fig. 1 it can be seen that there was almost always a plasma flux at values of $E/Q = 1664$ and 2476 volts (corresponding to proton velocities of 563 and 690 km/sec). Only occasionally during this period did E/Q become as low as 516 volts (314 km/sec) or as high as 8224 volts (1250 km/sec).

Table 1 is a summary of the percentage of time the peak of the measured spectrum fell in each of the windows of E/Q.

There were eight geomagnetic storms during the period 29 August through 31 October. The geomagnetic storm which started at 2025 hours universal time, on 7 October has been studied in some detail. A sudden increase in plasma flux and energy occurred at about 1547 on 7 October, when the spacecraft was 8.55×10^6 km closer to the sun than the earth was. If one assumes that this plasma front was advancing with spherical symmetry and constant velocity from the center of the sun (at least for the region of space containing the spacecraft and the earth), then the velocity

Table 1. Distribution of E/Q of the peak of the solar plasma spectrum.

E/Q (volt)	Time (in %) during which measured current in E/Q was the maximum	Time (in %) during which measured current in two adjacent channels of E/Q was approximately equal
516	0.0	
		0.2
751	18.3	
		2.0
1124	22.5	
		2.2
1664	30.5	
		4.0
2476	19.9	
		0.1
3688	0.3	
Total	91.5	8.5

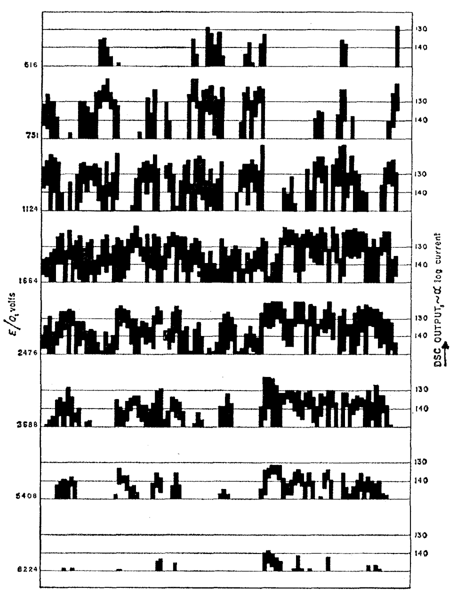

Fig. 1. Summary of plasma flux as a function of E/Q and time for the period 29 August through 31 October.

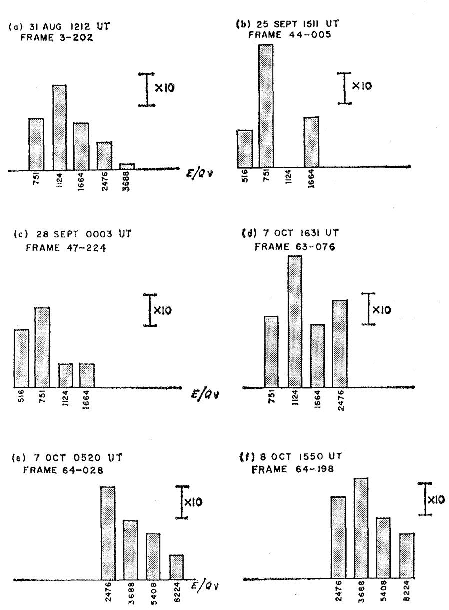

Fig. 2. Selected plasma spectra.

of the front was 504 km/sec. This velocity corresponds fairly well to the measured plasma spectrum, in which more current was measured at the value of E/Q which corresponds to a proton velocity of 464 km/sec than at 379 or 563 km/sec.

This discontinuity, or plasma front, passed the spacecraft so quickly that the instrument, with its 3.7-minute time resolution, could not resolve its structure, which must therefore be less than 112,000 km thick. The Mariner magnetometer data for this period could be interpreted as showing a front of thickness of the order of 50,000 km.

Another interesting feature of the plasma spectrum for this period is that the energy of the ions in the plasma kept increasing for approximately one day after the passage of the initial front. The plasma density, however, increased very rapidly, by a factor of about 5, and then returned to below its prestorm value about 5 hours after the storm front passed.

The plasma associated with the seven other geomagnetic storms exhibited similar behavior, although it is more difficult to identify the storm front for these other storms.

A few selected spectra are given in Fig. 2. An outstanding feature of many of the spectra is the presence of two peaks, the lower-voltage peak being the higher of the two. Due to the relatively wide spacing of values of E/Q for which the flux was measured, it is not possible to prove whether or not two peaks were always present. The most probable explanation of the presence of two peaks is that the lower-voltage maximum is due to protons while the higher-voltage maximum is due to alpha particles with approximately the same velocity away from the sun as the protons (and thus twice the value of E/Q).

Another consequence of the wide spacing of values of E/Q is the difficulty in determining the density and temperature of the plasma. Estimates have been made for only a few spectra so far. The values for spectra *a* and *f* of Fig. 2 were estimated on the basis of a model in which the plasma flows directly from the sun with a bulk velocity v_o, density n, a proton temperature T in the direction of motion, and zero proton temperature perpendicular to the direction of motion, with results as follows: For spectrum a—$v_o = 460$ km/sec, $n = 2.5$ cm^{-3}, $T = 1.9 \times 10^5$ deg K; for spectrum f—$v_o = 810$ km/sec, $n = 4.5$ cm^{-3}, $T = 7.4 \times 10^5$ deg K. These figures were based on the further assumption that the currents at the three lowest values of E/Q were due to protons only.

Another model which we hope soon to be able to compute has equal proton temperatures parallel and perpendicular to the direction of motion. In this respect, it should be noted, the plasma flow observed by Explorer X was consistent with ion temperatures of 4 to 8×10^5 deg K (*1*).

If we assume that the values of v_o, n, and T given above are approximately correct, and if we further assume an average value for the interplanetary magnetic field of $B = 5$ gamma $= 5 \times 10^{-5}$ gauss, we can compute the following important parameters for spectrum *a*, which appears to be fairly representative of quiet, non-storm conditions during the period of observation: Plasma flux $= nv_o = 1.2 \times 10^8$ cm^{-2} sec^{-1}; plasma energy density $= n(\frac{1}{2} mv_o^2 + \frac{1}{2}kT \approx \frac{1}{2}\ nmv_o^2 = 4.4 \times 10^{-9}$ erg cm^{-3}; magnetic field energy density $= B^2/8\pi = 1.0 \times 10^{-10}$ erg cm^{-3}; Alfvén velocity $= v_A = B/\ (4\,\pi\, mn)^{\frac{1}{2}} = 69$ km sec^{-1}; $v_o/v_A = 6.7$.

From these computations, conclusions can be drawn as follows:

1) The plasma flux is in good agreement with the values found by Explorer X (*2*) and by the ion traps on the Lunik satellites (*3*).

2) However, the plasma velocity v_o appears to be greater than that observed close to the earth by Explorer X. The measured velocity agrees fairly well with the value predicted from Parker's "solar wind" theory (*4*) but is higher than the value predicted from the observation of comet tail orientations (*5*) and much higher than the values predicted by "solar breeze" theories (*6*).

3) The plasma energy density is much greater than the energy density of the magnetic field. Thus we may conclude that the magnetic field in interplanetary space is carried along by the plasma, the field giving little or no hindrance to the plasma flow.

4) The flow of plasma about the earth and its magnetosphere is supersonic in the sense that the flow velocity is greater than the Alfvén velocity; this is probably a necessary condition for production of the predicted bow shock wave (*7*).

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23 November 1962

The Iowa Radiation Experiment

The primary purposes of the Iowa experiment in Mariner II are to search for charged particles magnetically trapped in the vicinity of the planet Venus and, if such particles are found, to obtain preliminary measurements of their spatial distribution and intensity. These measurements, when taken together with measurements by the magnetometer equipment on the same vehicle, should advance knowledge of the planet's internal constitution and its magnetosphere. The radiation equipment is also useful in monitoring the intensity of low-energy particles in interplanetary space during the 3½-month flight from the earth to the planet.

At present only the planets Earth and Jupiter are known to have extended belts of magnetically trapped particles. The belts of Earth have been studied by a comprehensive series of *in situ* observations with satellite and space probe equipment, those of Jupiter by radio-astronomical observations with ground-based equipment.

Current radar-astronomical evidence, obtained independently from the Millstone and Goldstone observatories, indicates that the angular rotational rate of Venus is of the same order of magnitude as the angular rate of its orbital motion around the Sun. Hence it is widely believed that Venus, by virtue of tidal friction during the evolution of the solar system, is now revolving about the Sun with its same hemisphere continuously facing the Sun. If this is indeed true, and if, despite such a low rotational rate of the planet, Mariner II finds a substantial intensity of trapped particles and a substantial magnetic field intensity (say, of the order of 100 gammas) at the expected miss distance of some 6.5 planetary radii from the center of the planet, then it would seem that profound revisions of general theories of planetary magnetism will be necessary. The implications of other combinations of conceivable outcomes of current work may be considered.

In planning the experiment it was thought most likely that the radiation belt of Venus, if any, would have a much lower intensity of particles than that of Earth and that the energy of these particles would also be lower. Other general considerations were the very limited weight, power, and telemetry allocations for this experiment and the necessity for the highest possible reliability. Our final choice of detector was an Anton type 213 Geiger-Mueller tube, which is a miniature tube having a 1.2 mg/cm^2 mica window about 0.3 cm in diameter. A number of such tubes have operated successfully in orbital flight for over 16 months in Injun I, throughout Explorer XII's lifetime of 4 months, and (as of the date of writing) for over 6 weeks in Explorer XIV. Some properties of the Mariner II detector are given in Table 1.

Table 1. Properties of the Iowa detector.

Type: Anton 213 Geiger-Mueller tube
Weight of 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
Maximum observable true counting rate by use of laboratory calibration curve: 10^7 count/sec

The tube also detects soft x-rays efficiently (~ 0.1 for 2-kev x-rays) and ultraviolet quite inefficiently (~ a few counts per second from a laboratory mercury arc whose ultraviolet intensity simulates that of the Sun). Although the x-ray sensitivity of this detector has valuable applications for studying x-ray bursts from the Sun and has been so used in Injun I, in the Mariner II apparatus special care was taken to shield it from both direct and reflected sunlight. The physical arrangement is shown in Fig. 1. No portions of the spacecraft lie within or near the conical aperture of the collimator. The axis of the spacecraft is stabilized to within less than 1 degree from the probe-sun line. (This angle is also measured and telemetered.) The sunshade of the tube's collimator prevents any sunlight from falling on any part of the collimator if the error in this angle is less than 10° in any plane; and the collimator itself prevents sunlight from falling on the window of the detector unless the axis of the detector is tilted toward the sun-probe line by more than 25 degrees, a situation which would correspond to a gross failure of the stabilization of the spacecraft. During flight to Venus, the spacecraft is gradually rolled around the probe-sun line in a systematic and known way in order to keep the directional telemetry antenna pointed toward the earth. The slow sweep of the axis of our detector across the celestial sphere may conceivably provide a significant search for sources of soft x-rays, but no analysis of the data from this point of view has yet been made.

The basic telemetry frame for the Iowa detector is 887.04 seconds in length. During each such frame the counting rate of the detector is sampled twice, at intervals separated by 37 seconds, as follows:

1) The number of counts during an interval of 9.60 seconds ("long gate") is accumulated on a shift register of seven binary stages. This register "overflows" on the 256th count.

2) The number of counts during an interval of 0.827 second ("short gate") is accumulated on a shift register of 15 binary stages. This register overflows on the 65,536th count.

Since the maximum apparent counting rate of the 213 detector is 50,000 per second the "short gate" system always gives a unique reading. At counting rates less than 26.6 per second the "long gate" reading is unique and has, of course, much better statistical accuracy than the "short gate" read-

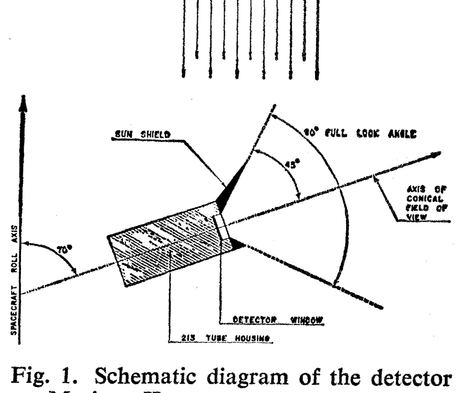

Fig. 1. Schematic diagram of the detector on Mariner II.