Zodiacal Dust: Measurements by Mariner IV

Abstract. *Data from the Mariner IV dust-particle experiment reveal an increase by a factor of 5 in the flux of interplanetary dust particles as the heliocentric distance from the sun increases. There is a variation in the slope of the cumulative flux-mass distribution, with the steepest slope for the distribution occurring between the planets. No enhancement of the flux in the vicinity of Mars was detected.*

The objective of the cosmic-dust experiment on Mariner IV was the measurement of the mass and flux distributions of interplanetary dust particles in the vicinity of the earth, between the orbits of the earth and Mars, and in the vicinity of Mars. Prior to the Mariner IV mission, the primary information concerning these dust particle distributions had been obtained from analysis of photometric studies of the zodiacal light, solar corona, gegenschein (counterglow), and the cosmic-dust experiment on Mariner II (*1*). The major features of the measurements from the cosmic-dust experiment on Mariner IV are: (i) an enhancement of the flux as the heliocentric distance from the sun increases; (ii) a change in the cumulative flux-mass distribution curve with the flux varying as a function of $m^{-0.55}$ (m, mass) near both planets to $m^{-0.9}$ between the planets; (iii) no statistically significant evidence of any well-defined dust particle streams; (iv) no measurable enhancement of the flux in the vicinity of Mars; and (v) the flux measured by the Mariner II experiment is consistent with the measurements from the Mariner IV instrumentation near 1 AU, which indicates that the flux, between 0.72 AU and 1.2 AU is fairly constant.

The experiment detector consisted of an aluminum sensor plate (area = 3.5×10^{-2} m^2) with an acoustical transducer bonded to this plate. In addition, a thin film capacitor covered each side of the plate providing another detector sensitive to high speed microparticle impacts. The impact plate was mounted in such a manner that each side of this sensor was exposed to cosmic dust impacts. The acoustical transducer produces a signal related to the mechanical impulse received by the sensor plate from a dust particle impacting on either side of the plate. The capacitor sensors detected the side of the plate on which an impact occurred. The electronic instrumentation contained a storage system which accumulated all dust-particle impacts and provided eight levels of pulse-height analysis to the signal from the acoustical transducer. This system also provided information concerning the occurrence of coincidences between signals from the acoustical transducer and the capacitor sensors. The threshold sensitivity of the acoustical transducer was $6 \pm 0.7 \times 10^{-5}$ dyne-sec. The dynamic range of the pulse-height analyzer extended to 1.96×10^{-3} dyne-sec. The system simply counted particles for which the momenta were larger than 1.96×10^{-3} dyne-sec. The instrumentation also contained an experiment calibration which was performed approximately three times a day when the telemetry was on the high bit rate, and approximately once a day when the telemetry was on the low bit rate. The viewing solid angle of the system was approximately π steradians.

The measurements reported here cover the period of time which starts at approximately 10 hours after launch (0000 U.T., 29 November 1964) and goes through the encounter with Mars (approximately 0100 U.T., 15 July 1965). All in-flight calibrations of the experiment instrumentation were proper in all respects. Of the 215 impacts recorded, 18 occurred during times when, for various reasons, the telemetry stations were not receiving transmission from the spacecraft. The experiment accumulator recorded these events, but no pulse-height analysis information was available. Pulse-height analysis information was obtained for the remaining 197 impacts.

The preliminary data are presented in Table 1. Between 1 and 1.25 AU, the cumulative flux was 7.3×10^{-5} particle m^{-2} sec^{-1} (π steradian)$^{-1}$. As the distance of the spacecraft from the sun increased, the measured flux also increased and reached a peak of 3.3×10^{-5} particles m^{-2} sec^{-1} (π steradian)$^{-1}$ between 1.36 and 1.43 AU. The flux then decreased to 1.8×10^{-4} particle m^{-2} sec^{-1} (π steradian)$^{-1}$ at encounter with Mars. From the data in Table 1, the measurement indicates a flux enhancement of a factor of 5 as the heliocentric distance from the sun increased. The maximum flux occurred at a heliocentric distance roughly equal to the perihelion distance of Mars (1.38 AU).

Table 1. Cumulative flux-mass distribution for various heliocentric distances. N_p, number of impacts; Δt, time in days with first data interval starting at 0000 U.T., 29 November 1964, and last interval ending at 0100 U.T., 15 July 1965; psd, probe-sun distance in AU for each data interval; Φ, mean cumulative flux for each data interval in particles m^{-2} sec^{-1} (π steradian)$^{-1}$; β, slope of cumulative mass distribution.

N_p	Δt (days)	psd (AU)	Φ	β
44	100	1.0 –1.25	7.3×10^{-5}	−0.5
43	34	1.25–1.36	2.1×10^{-4}	−0.9
40	20	1.36–1.43	3.3×10^{-4}	−0.6
39	29	1.43–1.49	2.2×10^{-4}	−0.55
49	45	1.49–1.56	1.8×10^{-4}	−0.6

The cumulative flux for each interval listed in Table 1 can be related to particle mass by an expression of the form: $\Phi \, \alpha \, m^{\beta}$. The values of β for the intervals shown in Table 1 demonstrate the variation of the flux-mass distributions between 1 and 1.56 AU. With one exception, the value of β generally varies between −0.5 and −0.6. The exception to this value of β is in the second interval in Table 1, for which a value of −0.9 was obtained. In general, the value of β for the flux-mass distribution is the same in the general region of the two planets, but a steeper slope of the distribution was measured between the planets.

A comparison can be made between the flux indicated by the Mariner II measurement where two impacts were recorded. The flux and mass distributions for the first interval in Table 1 indicate that 3 ± 2 impacts could be expected from the Mariner II measurement. Since the Mariner II result is consistent with the data from the first interval of the Mariner IV measurement, the flux and mass distributions between 0.72 and 1.25 AU may be similar.

The Mariner IV experiment provides the first opportunity to compare direct measurements of flux-mass distributions of dust in the zodiacal cloud with those made with ground-based photometric instruments. Previous analyses (*2*) have come from satellite measurements of flux-mass distributions in the vicinity of the earth. In general, the flux-mass distributions obtained from the ground-based observations contain β approximately equal to −0.5 when large (10 to 100 μ in diameter) particles are assumed in the analysis. When analyses are made with the Mie theory of light scattering by small dust particles, steeper slopes for flux-mass distributions are obtained with $\beta \approx -0.9 \pm 0.1$ for much smaller particles (1 to 10 μ diameter). In addition, most of the analyses of flux distributions based on ground-based observations follow the assumption that decrease of flux is a function of increasing heliocentric distance. The measurement from Mariner IV shows a variation in the flux-mass distribution with the steepest slope of the distribution occurring between the planets. The measurement also yields a flux which increases with heliocentric distance from the sun. Neither of these results have been included in the analyses of ground-based photometric observations.

The experiment has been resumed after the playback of the pictures of the planet, and data are being obtained. Additional information concerning the apparent enhancement of flux near the perihelion distance of Mars may be obtained whenever there are communications with the spacecraft.

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Magnetic Field Measurements near Mars

Abstract. *During the encounter between Mariner IV and Mars on 14–15 July, no magnetic effect that could be definitely associated with the planet was evident in the magnetometer data. This observation implies that the Martian magnetic dipole moment is, at most, 3×10^{-4} times that of the earth.*

This is a preliminary report of the magnetic field measurements that were made near Mars on 14–15 July by the Mariner IV magnetometer. No effects definitely attributable to the presence of the planet were observed. This conclusion is based on a comparison of the encounter data with the measurements recorded by the same instrument within the region of interaction between the earth's magnetic field and the solar wind, as well as in interplanetary space during the 7-month interval between launch and encounter. It is assumed that the interaction of the solar wind with a significant Martian dipole moment would have produced effects geometrically similar to those observed near the earth, but with a scale determined by the magnitude of the dipole moment. This assumption is used to establish an upper limit for the Martian dipole moment. Since the bow shock (*1*) is the feature of a planet's interaction with the solar wind that occurs farthest from the planet (except possibly for the magnetic tail, which we were never in a position to detect because of the nature of the trajectory), the ability to detect such a shock forms the basis for our discussion. The ability of the Mariner magnetometer to detect a planetary shock front depended on the spatial resolution and sensitivity of the measurements, on the character of the interplanetary field fluctuations during encounter, and on the nature of the encounter trajectory.

The resolution of the telemetered magnetic data was 0.35 gamma per axis (1 gamma $= 10^{-5}$ gauss), a limit imposed by the uncertainty inherent in converting the magnetometer output analog signals to digital numbers before transmission to Earth. The noise threshold of the Mariner's vector helium magnetometer was significantly smaller, being equivalent to only 0.1 gamma rms per axis. Measurements were made in a 50.4-second cycle in which the intervals between consecutive simultaneous triaxial observations were 6.0, 3.6, 9.6, and 31.2 seconds after which the cycle repeated. During passage through the earth's bow shock, the sensitivity was the same, but each interval was only one quarter as long. Data obtained slightly behind the extended dawn line showed clear evidence of the geomagnetic bow shock as it repeatedly surged back and forth past the spacecraft (*2*). The region behind the shock front was characterized mainly by fluctuations about the mean with amplitudes of the order of 2 gamma and with prominent frequencies, as judged by the amount of change over the various lengths of the sampling intervals, of the general order of 0.1 cy/sec and lower. There were also changes of several gammas across the bow shock in the average components of the field. The bow shock around Mars should occur at a position where the field strength has a value determined by the solar-wind pressure (that is, its momentum flux), and hence the characteristics of the shock should be largely independent of the Martian magnetic moment and quite similar to what is observed at the earth.

Throughout the 7-month period in interplanetary space the Mariner magnetometer data show a pattern of alternating disturbed and quiet intervals which has come to be expected of these kinds of data and which is related to daily changes in solar activity. Fortunately the time interval before, and during, encounter was one of relative magnetic calm, even though the Mariner's energetic particle detectors were recording a solar proton event that began about 23 hours prior to encounter (*3*). During the interval from 1800 on 14 July to 0123 Universal Time, 22 minutes after closest approach, the field was unmistakably interplanetary in character, having fluctuations roughly an order of magnitude smaller than those behind the earth's bow shock. At 0123 U.T., a period of disturbance began abruptly with a 5-gamma jump in the field and an approximate doubling of the amplitude of the fluctuations. This condition continued for about 3 hours, after which the components returned to near their previous values. This disturbance could be interpreted as evidence for a weak bow shock associated with Mars, but our preliminary analysis does not exclude the possibility that it is just one of many similar disturbances seen in the 7-month period.

The Mariner flight path approached Mars from a direction 13° above the equatorial plane and at 0940 local time. It crossed the noon meridian at a latitude of −50° and an areocentric distance of 14,500 km or 4.3 r_M (Martian radii); it dipped down 21 minutes later to a latitude of −67° at closest approach, where the local time was 1435 and the areocentric distance 13,200 km or 3.9 r_M. Mariner did not pass into the shadow of the planet, but moved away in a direction making an angle with the Sun-Mars line of about