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THE MAGNETIC FIELD OF MARS: MARS 3 EVIDENCE REEXAMINED

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Abstract. Published reports permit the reconstruction of the Mars 3 trajectory on which the discovery of the Martian magnetic field by Dolginov and co-workers is based. Use of this trajectory to transform the original measurements and display them in geophysically oriented coordinate systems leads to the conclusion that the observed magnetic field was draped over the Martian obstacle as expected if the field were simply shocked and compressed solar wind magnetic field. There is no conclusive evidence that Mars 3 ever entered a Martian magnetosphere.

Introduction

When Mariner 4 flew past Mars in July 1965 it detected a disturbance of the magnetic field (Smith et al., 1965) that was later interpreted as a clear indication of a bow shock (Smith, 1969). The presence of a bow shock merely indicates that a significant fraction of the solar wind is deflected around the planet rather than absorbed by it. The key question in the interpretation of these data is the effective height of the obstacle. If the effective height is well above the ionosphere, then it is natural to assume that a planetary field is responsible for the solar wind deflection. Otherwise, it is most probable that some ionospheric process such as ion-pickup (Cloutier et al., 1969) or induced ionospheric currents (Michel, 1971) deflects the solar wind. Since the Mariner 4 shock encounter was far down the flank of the bow shock and since solar wind parameters were unavailable, extrapolation of the nose position and effective obstacle height were difficult. Dryer and Heckman (1967) estimated an effective obstacle height of 1620 km above the surface of Mars and concluded that Mars had a planetary field capable of standing off the solar wind. Spreiter and Rizzi (1972) estimated a height of 200 km and concluded that an ionospheric interaction was present.

At the time conventional wisdom was that Mars had no magnetic field (cf. Spreiter et al., 1970), so it was with some surprise that Dolginov et al. (1972; 1973) presented evidence for a planetary magnetic field based on Mars 2 and 3 measurements. Mars 2 was placed into a 1100 km by 28,000 km 18 hour orbit and Mars 3 into a 1100 km by 212,000 km 12 1/2 day orbit. Mars 2 spun slowly about the solar direction with unknown orientation in the transverse plane. Mars 3 was stabilized about all three axes but made relatively infrequent periapsis passes. The evidence for a planetary field as presented by Dolginov et al. is somewhat complex, based on a combination of arguments including the position of the bow shock, the identification of magnetopause crossings, and the simultaneous behavior of the plasma and the field. However, it rests most heavily on one pass of Mars 3 data taken on 1/12/72 from which Dolginov et al. deduce the direction and orientation of the magnetic moment of Mars. It is the purpose of this note to show that there is no reason to suppose that Mars 3 penetrated the Martian magnetosphere on this pass, that because of their locations all other putative magnetopause crossings are suspect and that the effective obstacle height is coincident with the height of the Martian ionosphere to within the accuracy of our knowledge of the proper scaling law for planetary bow shocks. We discuss the Mars 5 measurements of Dolginov et al. (1976) in a separate report.

The Position of the Bow Shock

We are not the first to point out that the Mars spacecraft crossed the bow shock too close to the planet to be consistent with a planetary field. Bogdanov and Vaisberg (1975) have used 24 shock encounters identified with ion detectors to make this point. Gringauz et al. (1976), using antisunward pointing electron measurements to identify the bow shock, claim otherwise. Comparison of the reported times of shock crossings on the same pass show indeed that the shocks identified by Gringauz et al. (1976) are slightly further out than those identified by Vaisberg et al. (1976). To be conservative we will use the Gringauz et al. identifications. Fitting these data with the technique of Holzer et al. (1972) (see also Russell, 1977), we obtain the shock front drawn in Figure 1. It has a nose distance 1.49 Mars radii from the center of the planet. If we use the terrestrial shock-magnetopause scaling (Fairfield, 1971), the obstacle nose radius is 1.12 R_M or the obstacle is at a height of 400 km, clearly consistent with ionospheric deflection.

If we use the gas dynamic analog for planetary ionospheric interactions (Spreiter et al., 1970) we obtain, for a Mach number of 8 and a ratio of specific heats of 5/3, an effective obstacle height of 1.01 to 1.24 R_M or an altitude range of 30 to 800 km depending on the assumed atmospheric scale height. One could argue whether it is indeed appropriate to use the terrestrial analog or the gas-dynamic analog. In defense of the use of the former we note that the scaling relationship between shock and obstacle depends on the shape of the obstacle, the Mach number of the flow and the ratio of specific heats. If the obstacle is indeed a magnetosphere the shape should be the same, and the effective ratio of specific heats should also be the same. The Mach number should change somewhat, but not much, since the density and field change from Earth to Mars such as to decrease the Alfven velocity only slightly, and the sound velocity is dominated by electrons which are nearly isothermal. In defense of the use of the latter, if the obstacle is not magnetic, the gas dynamic analog scaling law shows

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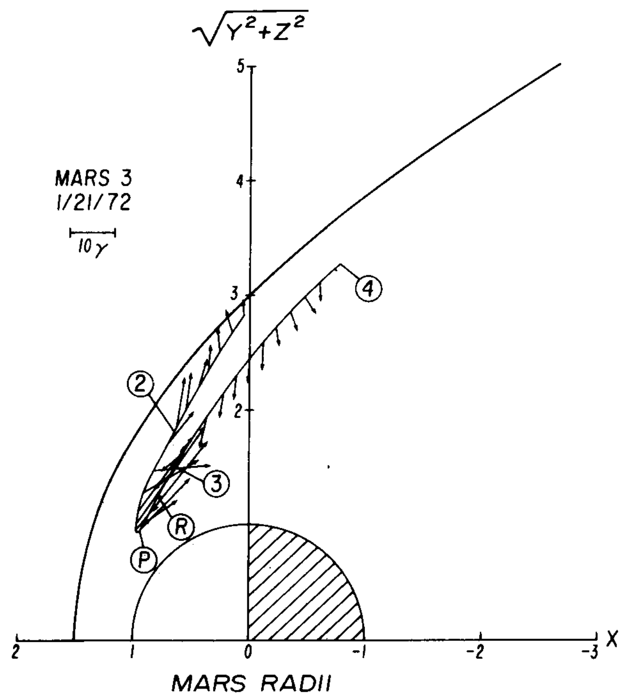

Fig. 1. The trajectory of Mars and the magnetic field measurements for the periapsis pass on 1/12/72 in the solar cylindrical coordinate system. The positions and field vectors have all been rotated into the plane defined by the solar wind, the planet and spacecraft position. Positions (2) and (3) denote magnetopause crossings as identified by Dolginov et al. (1973). Point (P) marks periapsis. Point (R) marks the reversal of the X-component of the magnetic field. Position (4) was identified as the outbound shock crossing.

that for reasonable conditions the effective obstacle height coincides with the ionosphere. We can safely conclude that with our present understanding of the scaling law between a planetary shock and the obstacle position, the data do not require that obstacle to be at a height greater than the ionosphere.

The Field Measurements of 1/12/72

Dolginov et al. (1972; 1973) published their magnetic field measurements in solar ecliptic coordinates but they did not publish the trajectory of Mars 3. While they never have published the full three components of the trajectory we have been able to reconstruct it with the X-Z projection of the trajectory published by Dolginov (1974), the altitude and the local time published earlier. These have been used in the construction of Figures 1 and 2.

With the three dimensional trajectory we can proceed. First we transformed the trajectory and field to a solar wind oriented system by rotating 4° in the ecliptic plane to take account of expected solar wind aberration. This is a minor correction. Then we constructed the field vectors and trajectory in solar cylindrical coordinates. In this system all vectors are rotated about the solar wind direction into a common plane (the plane containing the satellite, the planet, and the solar wind vector). This system is convenient for cylindrically symmetric situations.

As will be evident later, the bow shock is probably close to point (2). This is consistent with the identification of point (4) as the outbound shock encounter well inside its average position given by the solid line. Points (2) and (3) are the reported magnetopause encounters. They are surprisingly close to the average bow shock. Furthermore, they are at quite different distances from the planet despite the fact that they are almost at the same solar zenith angle. The other feature of interest in Figure 1 is a reversal of the solar-pointing component of the field at point (R). The existence and location of this reversal are perhaps the clearest indication that no planetary field was encountered and tell us what Mars 3 really encountered. To appreciate this indication we must first consider the nature of the draping of field lines around an obstacle in the solar wind.

The Draping of Field Lines

When a flux tube crosses the shock it is compressed. As it approaches the nose of the obstacle it continues to slow down and becomes even more compressed (Spreiter et al., 1966). However, the ends of the flux tube in the solar wind continue to move at their original rate. In the outer magnetosheath the field lines while moving slower than the solar wind still move much faster

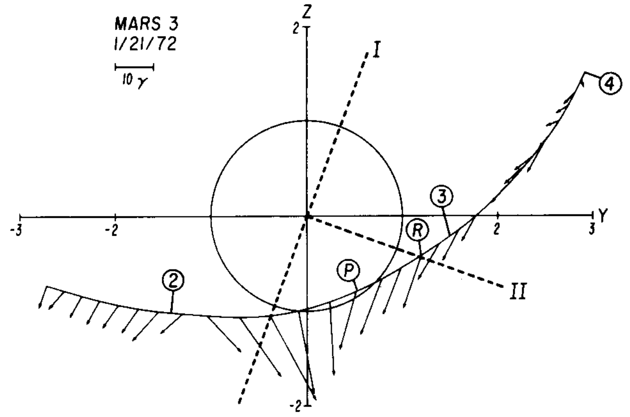

Fig. 2. The projection of the field and trajectory of Mars 3 on the Y-Z plane during the 1/12/72 periapsis pass. Points (2) and (3) mark positions identified as magnetopause crossings by Dolginov et al. (1973). Point (P) is periapsis. Point (R) marks the reversal of the X-component of the field. Dashed line I represents the field convected through the magnetosheath during the period between (P) and (3). Dashed line II is drawn perpendicular to I and the solar wind direction and represents the expected bending axis of the field. Since the field does bend around this axis, i.e., the X-component reverses sign at this point in the proper sense, then these field variations are consistent with the draping of field lines convected through the plasma sheet. Note that the largest field strength occurred as the spacecraft passed in front of the planet rather than at periapsis.

than the part of the flux tube near the nose. Hence the flux tube must bend. It bends about a line perpendicular to both the solar wind and the preshocked field direction. Eventually this bent flux tube slips around the obstacle but the overall geometry remains the same.

Figure 1 clearly shows a field configuration which resembles draping near the obstacle. The field vectors near Mars are roughly tangent to the planetary surface beneath the satellite. However, a magnetospheric field could also be so distorted. To distinguish a planetary and magnetosheath field we must examine the field in the plane perpendicular to the solar wind. Figure 2 shows this. This plot immediately reveals one further argument against a planetary origin for the field between (2) and (3). The maximum field strength is not at periapsis. It occurs as the spacecraft crosses the subsolar region, where a draped magnetosheath field would be expected to maximize. The observed changes do not appear to be consistent with the small azimuthal gradients observed in the terrestrial magnetosphere (Fairfield, 1968).

Since there may be some temporal variations during this pass we will use the orientation of the field surrounding the known position of the reversal in the X-component, as identified in Figure 1, to be the orientation of the field in the Y-Z plane at infinity. This dashed line is labelled I in Figure 2. Then we erect a perpendicular to this line through the center of the planet. This dashed line, labelled II, is the line about which the bending should occur. If there is a finite X-component of the field in the solar wind, we might expect the field reversal to occur somewhat about or below this line. However, here it is not displaced at all. This is consistent with the fact that such a large compression was seen on this pass. The coincidence of the field reversal with the bending line and the large field compression suggests that the field was nearly perpendicular to the solar wind during this pass. This inference is supported by the fact that, as shown in Figure 1, away from the planet the X-component of the field is small. Further, the sign of the X-component, toward the sun above the bending line and away below, is consistent with the general downward pointing field during the pass. We note also the convergence of field vectors as Mars 3 crossed the subsolar meridian suggesting a parting of the flow above the spacecraft, so that it could flow to either side of the planet, and the consequent distortion of the field. Finally, we note that in this plane there are no features which resemble magnetopause crossings such as field changes in the plane of the expected magnetopause. The configuration during whole pass is consistent with draping of field lines in a magnetosheath-like flow after passage through a shock in the neighborhood of point (2). We should emphasize that this analysis does not indicate whether the obstacle is a magnetosphere or ionosphere, since this same draping effect would be seen in either case. It indicates merely that there is no reason to conclude that Mars 3 entered the magnetosphere, rather Mars 3 remained on magnetosheath-like field lines at all times.

No further Mars 3 passes have been published by Dolginov and co-workers with which to repeat this analysis. Since Mars 2's orientation is unknown, we cannot use its data either. However, we can check the locations of the reported magnetopause crossings. These turn out to be similar to those discussed here, i.e., unexpectedly close to the shock front. We can repeat the analysis for Mars 5. All these passes are behind the planet. An analysis of these crossings suggests that these data can also be explained in terms of draping (Russell, 1978).

Discussion

Wallis (1975) has also expressed doubt about the existence of a Martian magnetosphere. In particular he questions the identification of the bow shock identified by Dolginov et al., suggesting instead that the non-thermal electrons and the magnetic fluctuations seen before encountering point (2) were "upstream" effects and that point (2) is in fact the bow shock. Wallis further notes that inspection of Figure 3 of Vaisberg et al. (1973) reveals that thermalized, i.e., shocked, ions did not appear on this pass until point (2). Thus, Wallis' interpretation of these data, but based on the characteristics of the plasma rather than the magnetic field, is totally in accord with ours.

To theoreticians the fact that Mars may not have a significant planetary moment is not surprising. In fact, Young and Schubert (1974) have argued that Mars' core has already frozen. Furthermore, if Mars did have an active dynamo the field should be much larger than Dolginov et al. reported. This is true whether we use the simple scaling law based on angular momentum (cf. Siscoe, 1978) or more sophisticated models involving the size and properties of the expected Martian core (F. Busse, personal communication, 1977).

If we are ever to make an unambiguous determination of the planetary moment, we must make measurements much closer to the planet, either with orbiters directly behind the planet or with measurements on the surface. We note that even if Mars turns out to have as little magnetism as the Moon, such measurements will prove useful to determining loss processes in the ionosphere and upper atmosphere, to sounding the Martian interior, and studying the evolution of the Martian magnetic field in a manner analogous to lunar studies.

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