THE MAGNETIC FIELD OF MARS: MARS 5 EVIDENCE RE-EXAMINED

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Abstract. The putative magnetotail encounters of the Mars 5 spacecraft cannot be scaled to the terrestrial magnetopause. Furthermore, the magnetic field during these claimed magnetotail encounters tends to be wrapped around the planet rather than rooted in it. There is no conclusive evidence that the Mars 5 spacecraft ever entered a Martian magnetosphere. The upper limit to the Martian magnetic moment is estimated to be $2x10^{21}$ Gauss-cm^3, or $2.5x10^{-5}$ of the terrestrial magnetic moment.

Introduction

All the evidence that Mars has a planetary magnetic moment is derived from the measurements of the Mars 2, 3 and 5 spacecraft. In a previous publication we argued that Mars 2 and 3 never penetrated a Martian magnetosphere (Russell, 1978). This argument was based on the fact that the reported "magnetopause crossings" were too close to the shock front to be magnetopause encounters and that the field seen inside the putative magnetosphere had the properties of draped magnetosheath field lines. This is not to say that the magnetic moment of Mars is zero. The above arguments show only that Mars 2 and 3 with periapsides near 1200 km over the Martian dayside did not penetrate the magnetosphere.

The Martian magnetic field, however, does not appear to be strong enough to stand off the solar wind flow. In a second paper in which we compared the shock fronts of the terrestrial planets, we found that the obstacle heights of Mercury derived by scaling from the observed bow shock positions, agreed with the observed size of its magnetosphere. The scaled obstacle heights for Mars corresponded to the ionosphere and for Venus below the ionosphere (Russell, 1977). Furthermore, the shapes of the bow shocks of Mercury and the Earth were most similar, and the shapes of the bow shocks of Venus and Mars were most similar, again suggesting the similarity of the Venus and Mars interactions, and their contrast with the magnetospheric-type interactions of the Earth and Mercury.

The Mars 5 data are potentially more sensitive for detecting a planetary field because of characteristics of the Mars 5 orbit (Dolginov et al., 1976). Although Mars 5 does not pass directly behind the planet, it does penetrate close enough to the wake axis to see the magnetotail which would arise from a planetary dipole moment much smaller than the $2.5x10^{22}$ Gauss-cm^3, or $3x10^{-4}$ of the earth's magnetic moment, reported by Dolginov et al. (1973). It is the purpose of this article to examine the magnetic field data from the Mars 5 spacecraft to see if there is any evidence for penetrations of a Martian magnetotail by Mars 5.

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The Trajectory

Although many passes of Mars 5 magnetic field data have been published, three dimensional trajectory information is available for only two of them, the passes on 2/13/74 and 2/20/74. In order to correct for the aberration of the solar wind and to project the field into geophysically useful coordinate systems along the trajectory we need the trajectory data for all the orbits. To do this we first calculated the time of periapsis for every orbit from the altitude time profile which was available for each orbit. Then we assumed that in inertial space the orbit plane remained fixed, and in solar ecliptic coordinates the projection of the orbit on the ecliptic rotated due to the planet's motion about the sun. Thus we were able to reconstruct from the 2/13/74 pass each orbit in February 1974 which includes all the published field data. We checked our calculations by comparing our predictions with the given orbital positions for 2/20/74 and found them to be accurate within a few hundred km in each of the 3 orthogonal solar ecliptic directions.

The Boundary Crossings

Figure 1 shows all the published trajectories. The triangles indicate shock crossings as identified by Dolginov et al. We note that 3 of the 4 shock crossings lie inside the average shock surface obtained by fitting the shock positions of Gringauz et al. (1976). As illustrated in Figure 2, Dolginov et al. have tended to locate shock crossings at their outermost possible position rather than at their most probable position. If the location of the main field jump is chosen then all of Dolginov's shock crossings lie well inside the shock surface of Gringauz et al. lending additional credence to the ionospheric nature of the obstacle.

The open squares denote magnetopause crossings in which the field in the putative magnetotail was away from the sun. The closed squares denote magnetopause crossings in which the field in the magnetotail was toward the sun. The closed dots indicate claimed magnetotail exits. The three lines, dot-dashed, dashed, and dotted, have the shape of the terrestrial magnetopause and magnetotail as determined by Fairfield (1971). If the only difference between the interaction of the solar wind with the earth and with Mars were the relative strength of the dipole moments and the solar wind dynamic pressure, then the shape should remain invariant and only the dimensions would be different. The dot-dashed line is the scaled magnetopause consistent with the observed stand off distance of the shock (Russell, 1977). The dashed line is the scaled terrestrial magnetosphere consistent with the magnetotail exits. The dotted line is the largest scaled terrestrial

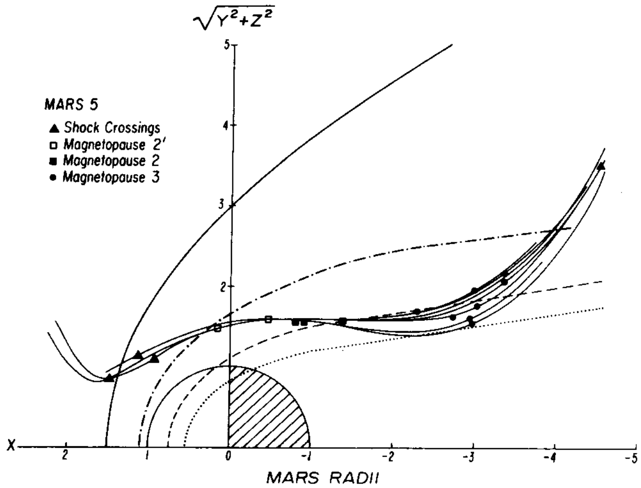

Fig. 1. Magnetopause and shock crossings by Mars 5 reported by Dolginov et al. (1976). The X-direction is along the expected solar wind direction, 4° from the Mars-sun line. The Mars 5 spacecraft moves from left to right in this display. The squares denote putative magnetotail entrances; the dots magnetotail exits. The dot-dashed curve is the largest magnetosphere consistent with the observed shock position. The dashed line shows a scaled terrestrial magnetopause consistent with the interpretation of the dots as magnetotail exits. The dotted line shows a scaled terrestrial magnetopause consistent with the hypothesis that Mars 5 never entered the magnetotail. Note that no scaling of the terrestrial magnetosphere can be made to fit both the entrances and exits. The identification and numbering of the crossings follows that of Dolginov et al.

magnetosphere consistent with the hypothesis that Mars 5 never entered the magnetotail. The dot-dash curve, while consistent with the shock position, is inconsistent with the observed tail crossings. The dashed curve while consistent with the exits from the magnetotail is inconsistent with the entrances.

In short we cannot simply scale down the terrestrial magnetosphere to Mars. One possible explanation is a difference between the relative importance of tangential and normal stresses in the two magnetospheres. However, this difference should also occur at Venus, yet the Venus tail has a flare similar to that of the earth's (Russell, 1976), while the Mars tail, if these identifications are correct, obviously does not. Another possibility is that Mars does not have a magnetotail. This possibility is discussed in more depth below. Finally, if the scaled magnetotail, which is consistent with observations, has an equivalent stand off distance below the planetary surface, as is the case for the inner two magnetopause shapes in Figure 1, the ionosphere must play an important role in the interaction even if there were a magnetotail.

The Magnetic Field Measurements

The above evidence is very suggestive that Mars 5 did not encounter a magnetotail resembling the terrestrial magnetotail in shape but the evidence does not preclude a magnetotail not resembling the terrestrial magnetotail. In order to test whether the data are consistent with a new type of magnetotail we must define some criteria for such a magnetotail. We will count as a possible magnetotail any region of space near the wake of the planet where the field appears to be rooted in the planet. Thus the field must point either roughly towards or away from the planet and have only a small divergence from the wake axis. A convergence towards the tail axis is not considered to be a magnetotail-like characteristic. Furthermore, the field cannot have a large azimuthal component around the tail axis. A large azimuthal component is characteristic of magnetosheath fields which drape around the wake axis. To check this latter property we must check the projection of the field and the trajectory perpendicular to the Mars solar wind line. We note that the magnetotails of Mercury, Venus and the earth satisfy these criteria (Ogilvie et al, 1977; Russell, 1976).

We have chosen to present two of the Mars 5 passes which are two of the most complete orbits but are typical of all the orbits. Figures 2a and 3a show the orbit and field projected into the so-called X-ρ plane defined by the sun-Mars direction and the Mars-spacecraft vector. We note that the use of such a display is tantamount to assuming cylindrical symmetry. In justification of this assumption we note that Romanov et al. (1977) have shown that the Venus tail and shock deviate only slightly from cylindrical symmetry.

The numbers 1, 2, and 3 were assigned by Dolginov et al. to features they identified to be the shock crossings, entrances into the magnetosphere and exits from the magnetosphere. Entrances into the magnetosphere with polarity opposite that normally observed were designated 2'. It is not obvious in Figure 2a why point 2' was chosen as a magnetopause crossing. Only part of

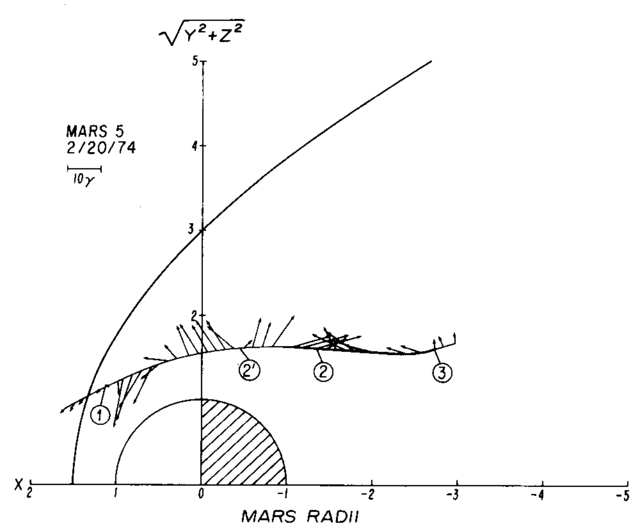

Fig. 2a. The Mars 5 magnetic field trajectory in solar cylindrical coordinates (same display as Figure 1) for 2/20/74. The heavy line starting between 2' and 2 and ending at 3 shows the low velocity zone identified by Vaisberg et al. (1976).

the time near point 2 does the field seem to be rooted in the planet. Looking at the orthogonal projection in Figure 2b we see that throughout the period from 2' to 3 the field has a significant azimuthal component around the tail axis. About the time of the "tail-like" field in Figure 2a, the field is decidely not tail-like in Figure 2b. We conclude there are no tail-like fields on this pass. The heavy line along part of the trajectory in Figures 2a and 2b indicate the region where the plasma velocity dropped to <150 km/sec (Vaisberg et al., 1976). We note that the entry into this region is not coincident with either of the two magnetotail entries but it is coincident with the exit. The onset of the low velocity region is coincident with a magnetic change between 2' and 2 as is the end of the low velocity region at 3. However, throughout the low velocity zone the field is not characteristic of a magnetotail. It appears that this region is simply a planetary boundary layer not intimately connected with the formation of a magnetotail.

Examination of Figures 3a and 3b tells a similar story. No plasma data are available for this pass. Figure 3a displays tail-like field only in the region half-way between points 2 and 3 and the solar pointing component is weak. In contrast the azimuthal component shown in Figure 3b is much stronger. In fact in the Y-Z plane there is very little change in the orientation of the field throughout the pass. The field appears to be simply draped magnetosheath lines. The pass that came closest to the wake axis was that on 2/13/74, and the data are almost identical except that the solar pointing component is slightly stronger.

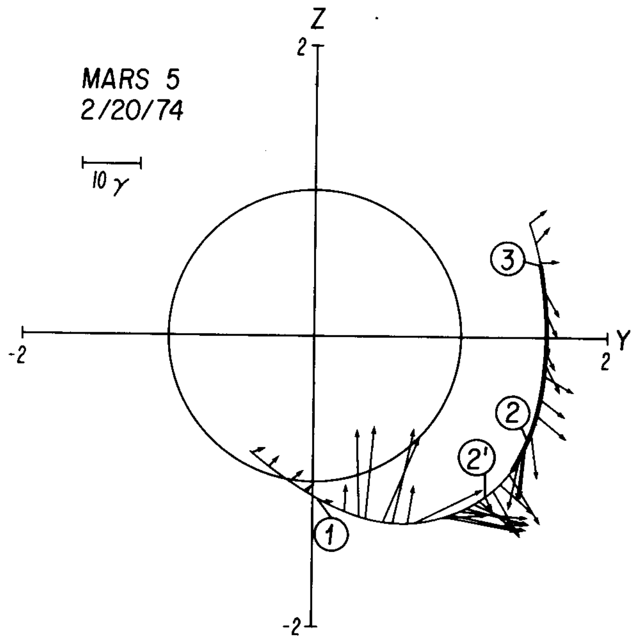

Fig. 2b. The Mars 5 magnetic field and trajectory in the plane perpendicular to the solar wind flow. The Z-direction is toward the north ecliptic pole.

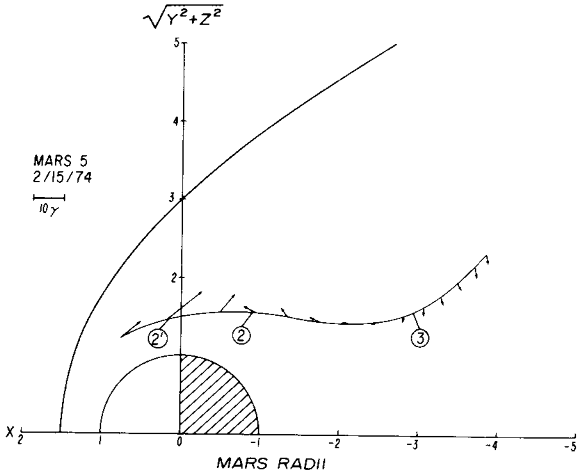

Fig. 3a. Same display as Figure 2a but for 2/15/74.

Discussion

There is no clear evidence in these data that Mars 5 ever penetrated a Martian magnetotail. This is not to say Mars does not have some intrinsic field. However it is clear that the intrinsic field plays little significant role in the interaction of the planet with the solar wind. Figure 1 allows us to make some estimate of what an upper limit to this field might be. We recall that Dolginov et al.'s preferred moment of 2.5×10^{22} Gauss-cm^3 corresponds to a subsolar magnetopause radius of 1.6 R_M. If we use an obstacle height of 400 km above the surface corresponding to ionospheric deflection, a moment of 8.7×10^{21} is allowed. However, if we use the moment of the inner two scaled terrestrial magnetospheres in Figure 1, we obtain moments of 2.5×10^{21} Gauss-cm^3 and 9.8×10^{20} Gauss-cm^3 for the dashed and dotted curves respectively. Although we prefer the conclusion that the dotted tail boundary limit is the appropriate one, any planetary field would be less confined on the dayside than would be indicated by this boundary, so the upper limit might be as high as twice this limit. Thus our best estimate of the upper limit to the Martian moment is 2×10^{21} Gauss-cm^3, over an order of magnitude less than Dolginov and co-workers' value, and 2.5×10^{-5} times the earth's dipole moment.

Finally we note that Vaisberg et al. (1977) also reject a strictly magnetospheric interaction in favor of a combined atmospheric-magnetospheric interaction. They list as arguments against the magnetospheric interaction model: the mean position of the bow shock; the lack of ordered fields in the wake region and the control of the tail field by the IMF; the weak dependence of shock and magnetopause positions on external conditions; and the effects of viscous interaction in the external flow. However, they differ with our interpretation in that they feel they have identified a Martian polar cusp at a planetary longitude of about 330° in the near equatorial regions. We note however that this identification was made well behind the terminator over the nightside of the planet, whereas the terrestrial polar cusps are above the daylit hemisphere. Furthermore, an equatorial dipole moment would be

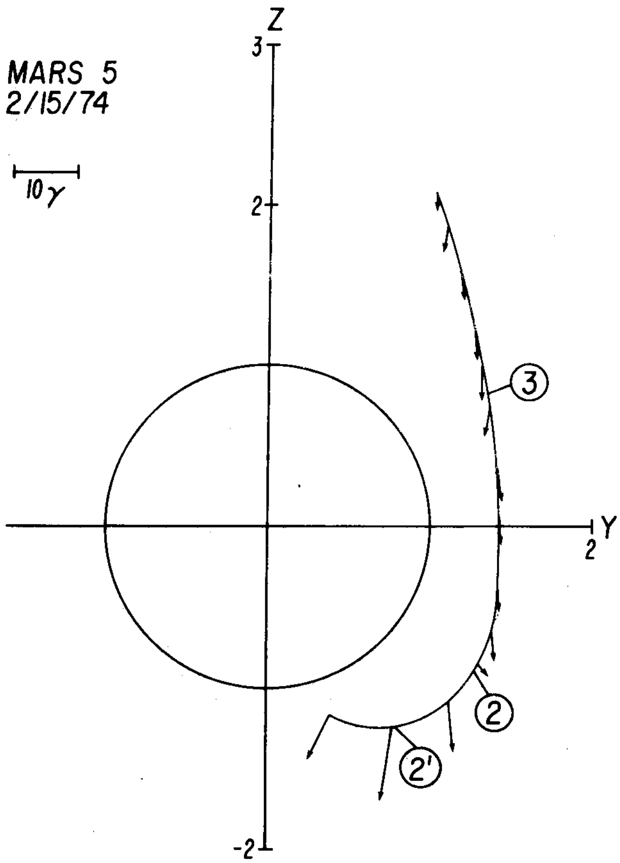

Fig. 3b. Same display as Figure 2b but for 2/15/74.

difficult to explain in terms of a dynamo model. Vaisberg et al. estimate the strength of the moment of this equatorial dipole to be about 1.3×10^{22} Gauss-cm^3. However, as noted above such a large moment should lead to a detectable magnetotail, and we see no convincing evidence that such a magnetotail has been detected.

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