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A SIMPLE TEST OF THE INDUCED NATURE OF THE MARTIAN TAIL

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ABSTRACT

The cross flow direction of the interplanetary magnetic field is strongly correlated with the cross flow direction several hours earlier and later. This correlation allows a simple test of the nature of the magnetic field in the Martian magnetotail. If the magnetotail is entirely induced, then the cross tail direction of the magnetic field should be along the direction of the cross flow component just upstream of the bow shock. We find that these directions of the tail field and the interplanetary magnetic field are so highly correlated that any intrinsic magnetic field of Mars must make at most a small contribution to the magnetotail. We estimate an upper limit to the magnetic moment of Mars to be about 4×10^{11} Tm^3.

INTRODUCTION

The search for the intrinsic magnetic field of Mars has now proceeded for 3 decades with no obvious success. An initial upper limit of 2×10^{13} Tm^3 was placed on the magnetic moment by the inferred size of the obstacle to the solar wind flow that was responsible for the bow shock detected by Mariner 4 /1,2/. Later Mars 2 and 3 measurements were interpreted in terms of the direct detection of a planetary magnetic field /3,4/ but these interpretations were questioned by others /5,6,7/ and magnetic moments as low as 10^{11}Tm^3 were estimated /8/. One of the important objectives of the Phobos mission was to resolve this question.

The Phobos mission had an initial elliptical phase when it approached the planet as close as 800 km, and a later circular orbit phase in which it circled Mars with an 8-hour period at the orbit of the moon Phobos. There was no clear resolution to the question of the strength of the Martian magnetic moment from these initial data /9/. The location of the current sheet in the tail was interpreted in terms of an induced magnetic field /10/. Spectral analysis of the tail field was interpreted both in favor of an intrinsic field /11/ and consistent with an induced field /12/. Distant bow shock crossings were interpreted as indicating an intrinsic field /13/ but such distant bow shocks also occur for non-magnetized planets such as Venus /14/. The pressure dependence of the size of the Martian tail was also offered as proof of the intrinsic nature of the Martian tail /15/ but this proof was based on an incorrect assumption of the behavior of the terrestrial tail /16,17/. Moreover, the behaviors of the Martian and Venus tails were found to be similar for similar solar wind pressures /18/. Thus every bit of evidence offered for the intrinsic nature of the Martian magnetic field has been questioned. It is the purpose of this paper to present a new test of the intrinsic versus induced nature of the Martian tail field which we believe is much less ambiguous than previous tests.

DATA ANALYSIS

Figure 1 shows the orbit of the Phobos spacecraft during the circular orbit phase. We divide the orbit into 16 one-half hour intervals and average over that period. To see how steady is the direction of the IMF we compare the angle of the field in the plane perpendicular to the solar wind flow with the same angle measured at earlier and later times. An example of such a comparison is shown in Figure 2. The horizontal axis shows the angle measured at time t_0 and the vertical axis shows the angle measured at time t_0 - 2.25 hours. (We obtain the value of 2.25 hours by using bins 2.0 and 2.5 hours earlier). We then perform a cross correlation between the two angles and find that they have a cross correlation coefficient of 0.93. If we repeat this for other separations and/or both preceding and following intervals we get the results in Table 1. In constructing this table we have used only sectors 1 and 8 as reference times. Over the range of time separations from 45 min to 3 h 15 min the correlation coefficient between IMF clock angle remains high, above 0.90.

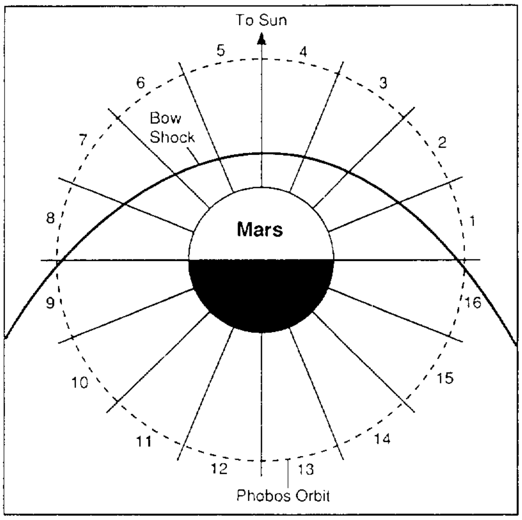

Fig. 1 Sectors used for averaging the Phobos magnetic measurements during the circular orbit phase of the mission. Sector 1 is the half hour period just sunward of the dawn terminator and the average bow shock.

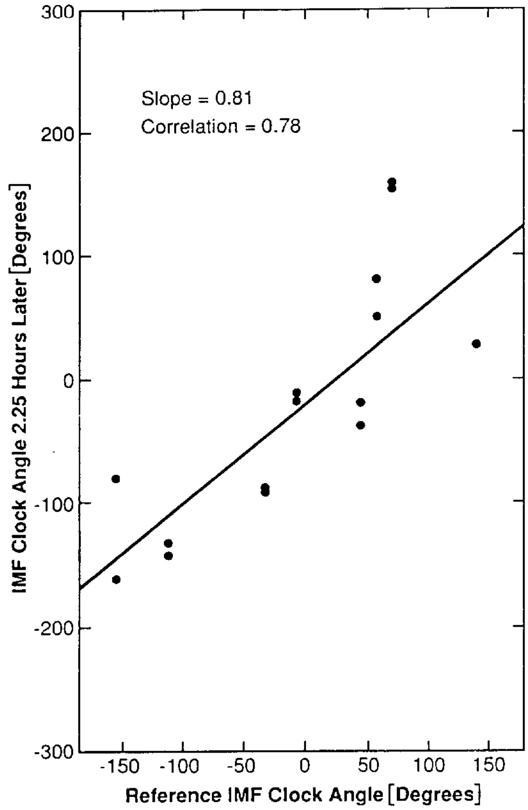

Fig. 2 IMF clock angle compared to earlier IMF clock angles. The shock angle is defined as the angle around the direction from the sun. Zero degrees is northward. Ninety degrees points opposite to planetary motion.

If we were to compare the IMF clock angle with that in the center of the tail, and if Mars had an intrinsic field we would expect these two angles to be uncorrelated. In Figures 3 and 4 we perform such a study comparing sections 12 and 13 in the center of the wake region with both sectors 1 and 8. Both figures show a very good correlation. The correlation coefficients for the entire wake and sheath passage are shown in Table 2. They are just as high as those in Table 1. Thus we must conclude that any intrinsic

Table 1. Inter-correlation of IMF Clock Angles

	Reference Time Preceding			Reference Time Following		
Separation Time[Hours]	No. of Points	Correlation Coefficient	Slope	No. of Points	Correlation Coefficient	Slope
0.75	20	.90	1.11	16	.98	.92
1.25	20	.91	1.13	16	.91	.83
1.75	21	.94	1.09	16	.78	.75
2.25	21	.93	1.19	16	.78	.80
2.75	19	.92	1.36	16	.82	.91
3.25	20	.91	1.47	15	.81	.97

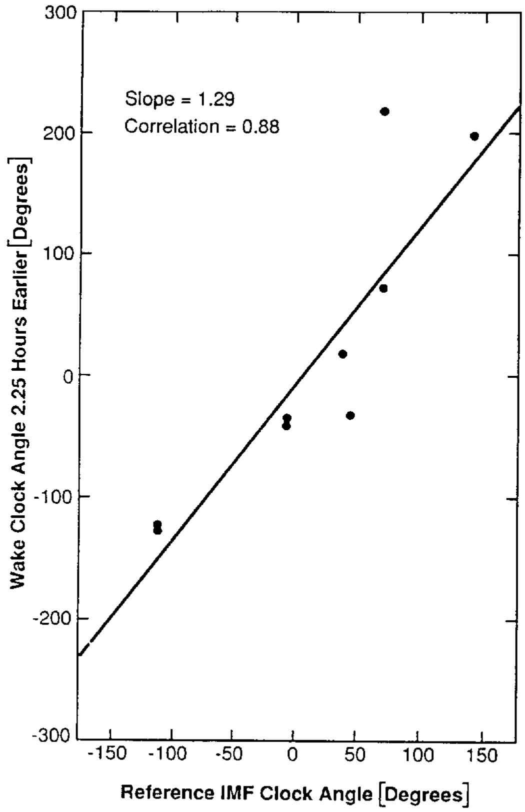

Fig. 3 Wake clock angles in sectors 12 and 13 compared with later IMF clock angles.

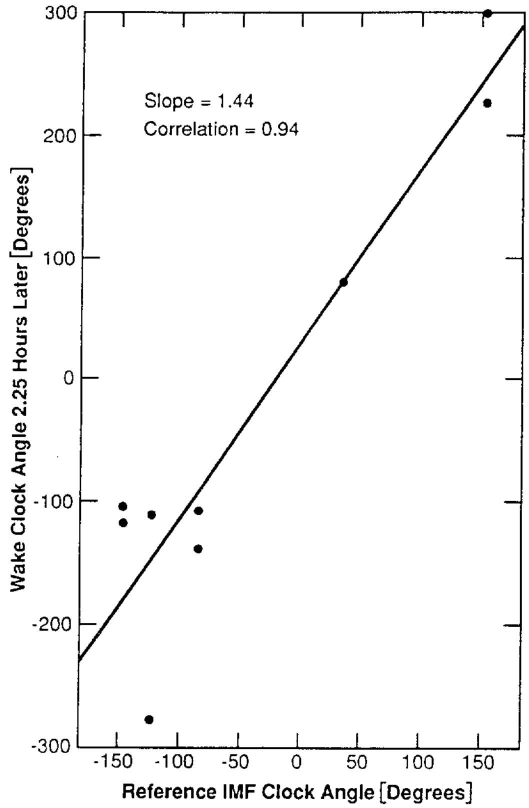

Fig. 4 Wake clock angles in sectors 12 and 13 compared with earlier IMF clock angles.

magnetic moment of Mars must not make a significant contribution to the magnetic field at a distance of 2.8 Martian radii behind the planet.

SUMMARY AND CONCLUSIONS

We have found no significant difference between the correlation of the IMF clock angle with itself and the correlation of the IMF clock angle with the clock angle of the magnetic field in the center of the tail at similar lags. We expect that a magnetotail with induced and intrinsic components could be found in either one of two states. The fields from the two sources could occur in separate regions of the tail or

Table 2. Cross-correlation of IMF Clock Angle with Sheath and Wake Clock Angles

	Reference Time Preceding			Reference Time Following		
Separation Time[Hours]	No. of Points	Correlation Coefficient	Slope	No. of Points	Correlation Coefficient	Slope
0.75	12	.98	1.45	24	.95	1.04
1.25	12	.98	1.29	19	.96	1.19
1.75	10	.92	1.42	11	.96	1.40
2.25	9	.88	1.29	10	.94	1.44
2.75	11	.93	1.64	11	.83	1.77
3.25	12	.87	1.56	12	.73	0.97
3.75	11	.71	1.09	13	.87	1.80

the fields could be interconnected. In the former case we would expect that we would see a clock angle that was totally unrelated to the IMF direction some fraction of the time. From the amount of uncorrelated variance allowed by our greater than 90% correlation coefficient, we estimate that Phobos is in regions of intrinsic magnetic field less than 10% of the time when it is in the center of the tail. Thus the planetary magnetic moment must be such that it contributes only about 10% to the force balance with the solar wind. Therefore, the magnetic movement must be less than about $4 \times 10^{11} Tm^3$. Alternatively since the average cross tail magnetic field at Phobos is about 6 nT and our uncorrelated variance could be due to a 10% contribution from an intrinsic field, the intrinsic field at the Phobos orbit could be as much as 0.6 nT. Terrestrial models and observations at comparable distances in the tail suggest that this could be provided by a planetary moment of about $3 \times 10^{11} Tm^3$. In short, our analysis has found no evidence for an intrinsic Martian magnetic field. We estimate that any intrinsic magnetic moment is less than about $4 \times 10^{11} Tm^3$.

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