Adv. Space Res. Vol. 12, No. 9, pp. (9)213–(9)219, 1992
Printed in Great Britain. All rights reserved.

0273–1177/92 $15.00

THE MARTIAN MAGNETIC FIELD ENVIRONMENT: INDUCED OR DOMINATED BY AN INTRINSIC MAGNETIC FIELD?

K. Schwingenschuh,* W. Riedler,* T.-L. Zhang,* H. Lichtenegger,*
H. Rosenbauer,** S. Livi,** G. Gevai, ** K. Gringauz,***
M. Verigin,*** Ye. Yeroshenko,† D. Möhlmann,‡ Th. Roatsch,‡
R. Lundin,§ C. T. Russell‖ and J. G. Luhmann‖

* *Space Research Institute, Graz, Austria*
** *Max -Planck Institute of Aeronomy, Katlenburg-Lindau, Germany*
*** *Space Research Institute, Moscow, Russia*
† *IZMIRAN, Troitsk, Moscow region, Russia*
‡ *Institute für Kosmosforschung, Berlin, Germany*
§ *Swedish Institute of Space Physics, Kiruna, Sweden*
‖ *IGPP/UCLA, Los Angeles, U.S.A.*

ABSTRACT

Even though magnetic field and plasma in-situ measurements near Mars from the 1989 PHOBOS-2 project and from earlier missions are available, the existence of an Martian intrinsic magnetic field is still controversial. In this study we analyze data of the PHOBOS-2 magnetic field experiments MAGMA and FGMM and use the upstream solar wind parameters of the TAUS and ASPERA experiments. Different methods are used to investigate the influence of the interplanetary magnetic field (IMF) and of a possible weak intrinsic field on the solar wind interaction with Mars : The compressibility of plasma boundaries, the correlation between upstream IMF and tail properties and between magnetic field structures and planetary rotation. The study shows that the magnetic field in the tail is strongly correlated with the upstream IMF suggesting that the Martian magnetotail is induced, at least to a large extent. Compressibility studies reveal a weak dependence of the plasma boundaries on the solar wind dynamic pressure but the bow shock location appears to be not affected by the Martian longitude within the accuracy of our measurements. We conclude that an intrinsic planetary field, if it exists, does not play a major role in the interaction between the solar wind and Mars.

INTRODUCTION

The first in-situ observation of the Martian plasma and magnetic field environment was made in 1965 when the Mariner 4 spacecraft passed the planet at a distance of about 3.9 Mars radii (1 $R_M = 3390$ km). A sharp increase of the magnetic field near the closest approach was interpreted as the crossing of a bow shock /1/. In 1971-72 the two orbiters MARS 2 and MARS 3 performed measurements down to 1100 km altitude and established the permanent existence of a Martian bow shock /2,3/. The magnetometer experimenters /4/ stated the existence of a Martian magnetic field based on observations of MARS 2, 3 and the 1974 MARS 5 mission. This interpretation of the measured field as planetary in origin has been called into question later /5/. The time resolution of the magnetic field and plasma instruments aboard these spacecraft was of the order of one sample per minute and the trajectory did not allow the study of the inner region of the Martian plasma environment or the central tail. The 1989 PHOBOS-2 mission provided for the first time the opportunity to study the Martian tail near its axis and the plasma environment

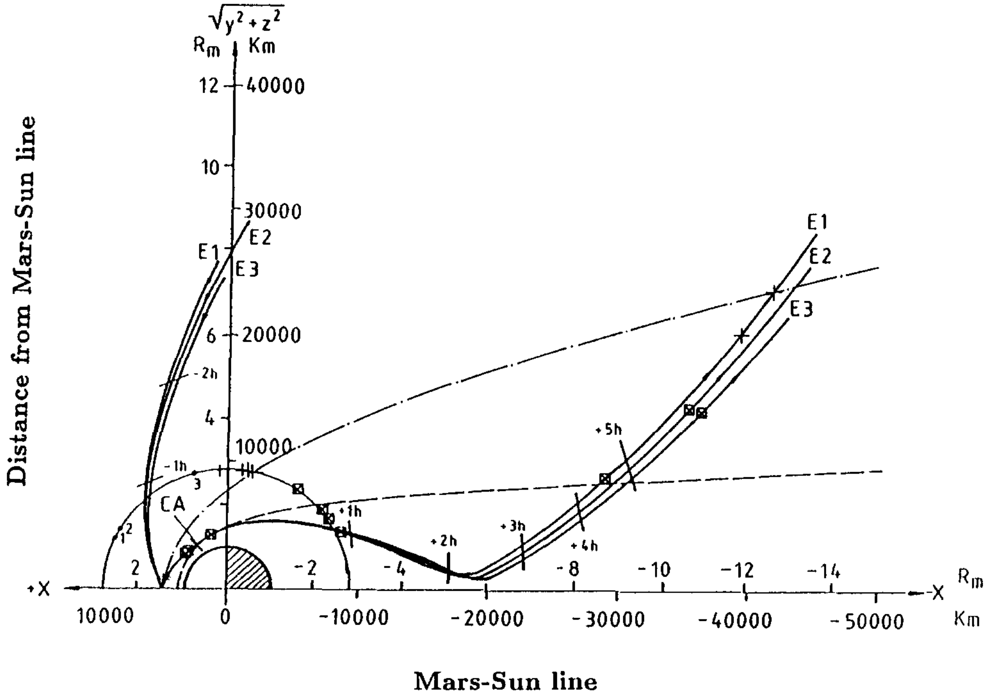

Figure 1: The main boundaries and events observed by the PHOBOS-2 magnetic field experiments MAGMA and FGMM during the first 3 low altitude elliptical orbits (E1,E2 and E3) and during circular orbits (outer semi-circle) around Mars. Tic marks indicate hours relative to the closest approach (CA). Square denote inbound and outbound crossings of the planetopause, crosses the position where the magnetometer observed the bow shock.

down to low altitudes (860 km). For the first time the spacecraft carried 2 magnetometers/6/, 3-D plasma instruments with ion-composition analyzers /7,8,9/ and a plasma wave analyzer /10/. After 5 highly elliptical orbits the spacecraft was maneuvered into an 8 hour circular orbit with a radius of 9600 km (Figure 1). Until the loss of the spacecraft on March 27, 1989 the field and particle experiments collected by far more data than obtained during the previous missions. This provided for the first time the opportunity to study the influence of the IMF and of a possible intrinsic magnetic field on the solar wind interaction with Mars on the basis of magnetic field data from about 50 orbits.

The type of the interaction of the solar wind with objects in the solar system depends mainly on their plasma or neutral environment and on the intrinsic magnetic field. In the case of a "magnetic" planet, e.g. the Earth, Mercury or Jupiter, the intrinsic magnetic field determines the shape of the obstacle. If the planet has only a small or no intrinsic field but an ionosphere, the shape of the obstacle depends mainly on ionospheric parameters. The deceleration of the solar wind due to massloading is typical for the cometary type of interaction. We know from in-situ measurements that Venus has no measurable intrinsic field and we have in-situ observation of the Martian magnetic field and plasma environment but the question of an intrinsic Martian magnetic field is still controversial.

Different methods can be used to investigate the influence of a potential intrinsic field or the IMF on the solar wind interaction with a planetary body:
- Magnetic field data from low orbiting spacecraft or from landing units (this method will be used during the MARS-OBSERVER and MARS-94 missions);
- Correlation studies of the upstream IMF and the magnetic field in the tail of the planet;

- Correlation between planetary rotation and plasma boundaries;
- Compressibility of the plasma boundaries.

THE CORRELATION BETWEEN THE UPSTREAM IMF AND THE MAGNETIC FIELD IN THE MARTIAN TAIL

In the case of a magnetospheric obstacle the dipole field of the planet determines the interaction with the solar wind and the magnetopause seperates the region dominated by the intrinsic field and the shocked solar wind region. In the case of an unmagnetized or weakly magnetized planet with an atmosphere an ionopause forms where the pressure of the ionospheric plasma balances the incident solar wind pressure. The common elements of both the magnetospheric and atmospheric obstacle include a bow shock and a region between the bow shock and the obstacle, known as the magneto(iono) sheath. Different type of tails form in the wakes of magnetospheric and atmospheric obstacles. The atmospheric obstacle exhibits a comet-like tail (induced tail) composed of IMF field lines, while the magnetospheric or intrinsic field obstacle forms a tail composed of stretched out field lines attached to the magnetic poles of the planet (intrinsic tail). The existence of a magnetotail is not by itself evidence for the existence of an intrinsic magnetic field. However, in constrast to intrinsic tails induced tails should be completely controlled by the IMF, in particular, the orientation of the neutral sheet should be at right angle to the IMF component perpendicular to the solar wind velocity vector. We plot in Figure 2 the two and half circular orbits of tail data that are inertially stablized and rotated dynamically according to the local

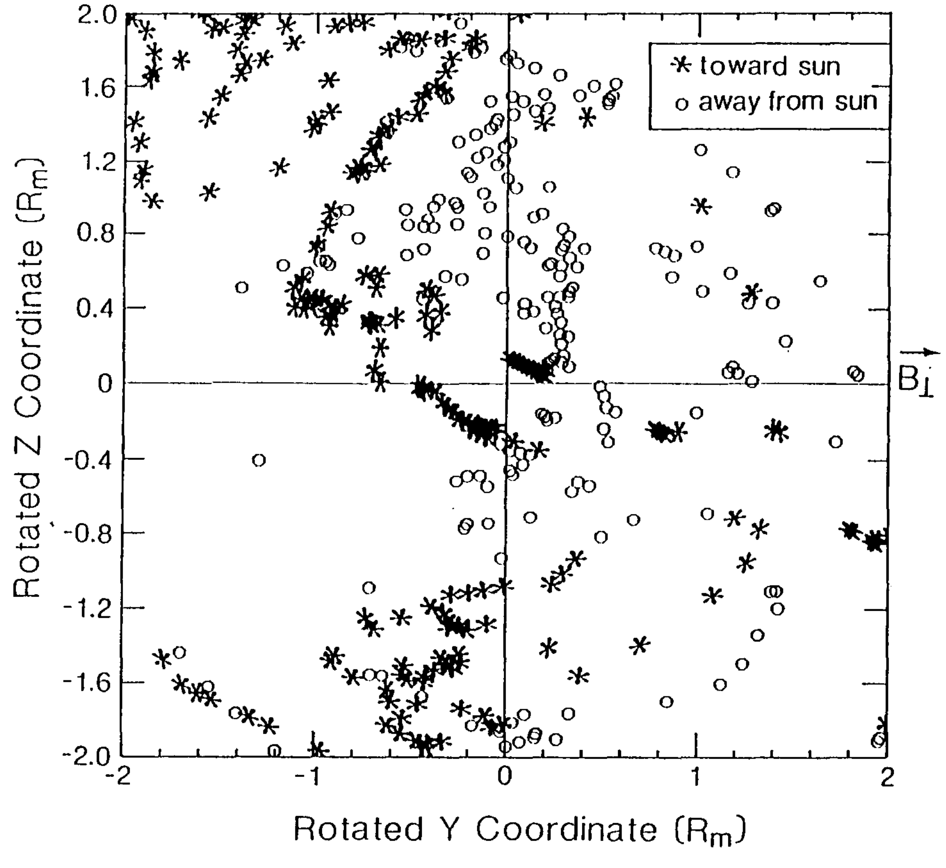

Figure 2: The two possible polarities of the magnetic field in the magnetotail. The view is down the tail. Open circles are fields away from the Sun (negative B_X and asterisks are fields toward the Sun (positive B_X). The coordinate system has been rotated for the average solar wind direction.

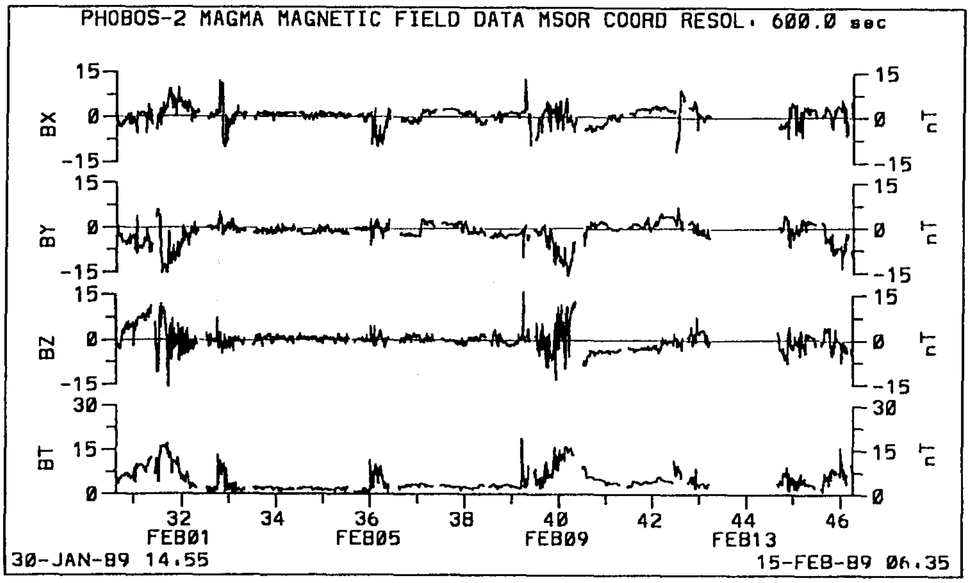

Figure 3: The magnetic field components and the total magnetic field observed during the elliptical orbits. The reversals of the X-components in the magnetotail of Mars have been used to deduce the induced character of the solar wind interaction with Mars.

direction of the cross tail field. Figure 2 shows that the polarity is predominantly determined by the perpendicular IMF direction indicating the induced character of the Martian magnetotail /11/. The polarity changes of the B_X component in the tail can also be seen on the time series plots of Figure 3.

CORRELATION STUDIES OF THE TERMINATOR BOW SHOCK RADIUS AND THE MARTIAN LONGITUDE

In a recent study of the PHOBOS-2 magnetic field data from the circular orbits it was found /12/, that the time series contain spectral peaks at 12 and 24 hours possibly indicating a corotating part of the magnetic field. This was interpreted in favour of the existence of a weak Martian magnetic field /13/. To test the hypothesis that these 12/24 hour peaks are caused by the variable bow shock locations observed by PHOBOS-2 /14/, we examined the magnetic field data of about 50 circular orbits. The bow shock crossings were fitted to the equation

$$R = \frac{L}{1 + \epsilon \cos(\mathrm{SZA})}$$

where R is the observed planetocentric distance, L the terminator distance, ϵ is the eccentricity and SZA the solar zenith angle in the aberrated coordinate system. The aberration angle of 2.7° was calculated using the average solar wind velocity of 500 km/s measured by the PHOBOS-2 plasma experiments (TAUS and ASPERA). An eccentricity ϵ of 0.8±0.1 was calculated from the bow shock crossings of the elliptical and circular orbits indicating that the shape of the bow shock is not changing very much. This is similar to the bow shock of Venus /15/. Figure 4 shows the calculated terminator bow shock radius assuming a fixed eccentricity of 0.8 plotted versus the areocentric longitude. If the variability of the bow shock location would have been caused by corotating features, e.g. strongly magnetized surface regions or a non-centered or not spin-aligned intrinsic dipole field, the scatter plot should show a distinct maximum at a certain longitude. But the plot shows no control of the bow shock location by the planetary longitude. The 12/24 h peak

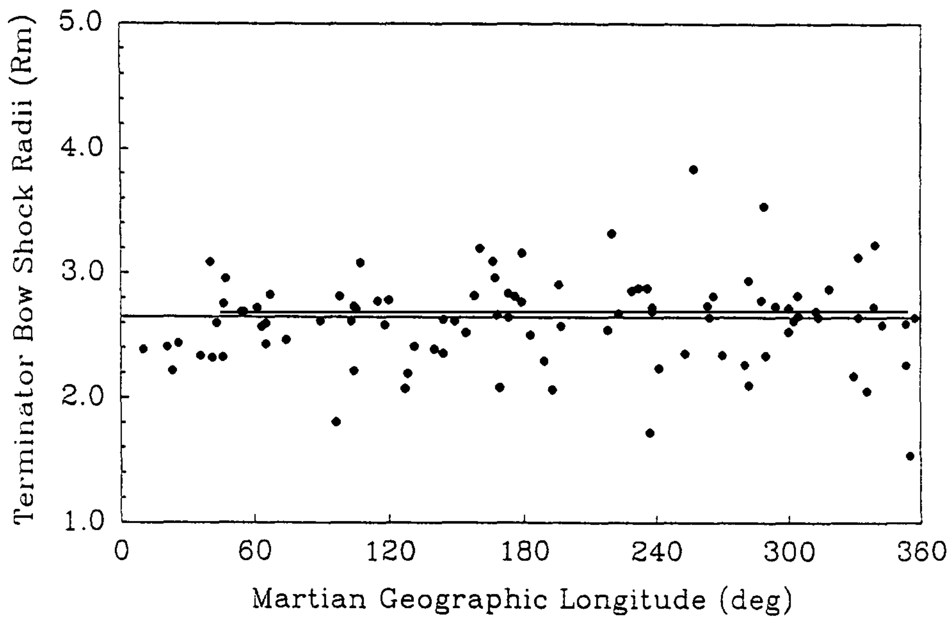

Figure 4: Scatterplot of the terminator bow shock radius (in Mars radii) versus the planetary longitude.

in the power spectrum must therefore be related to other structures in the magnetic field data. The correlation between the planetary longitude and other plasma boundaries will be studied in future.

THE INFLUENCE OF THE SOLAR WIND DYNAMIC PRESSURE ON THE BOW SHOCK RADIUS

The size of the terrestrial magnetosphere and consequently the terrestrial bow shock position is very sensitive to the dynamic pressure of the solar wind /16/. This compressibility is typical for intrinsic field obstacles. The compressibility of an atmospheric obstacle, e.g. Venus /17/ is much smaller. If Mars had a small intrinsic field the compressibility should be higher at low solar wind dynamic pressure /18/. Therefore we studied the dependence of the Martian bow shock terminator radius on the upstream solar wind dynamic pressure using the TAUS data. Figure 5 illustrates the variation of the terminator bow shock location and solar wind dynamic pressure during the circular orbits. Figure 6 shows the terminator radius plotted versus the dynamic pressure in arbitrary units. The circles show the individual measurements and the lines show the median values. As can be seen from the plots, the influence of the solar wind dynamic pressure on the location of the bow shock is only minor, in contrary to what is expected from a dipole intrinsic internal field. This indicates either a very small intrinsic field or a situation similiar to that on Venus when the EUV flux is high /17/.

CONCLUSIONS

The analysis of the PHOBOS magnetic field data revealed a strong correlation between the upstream IMF and the magnetic field in the Martian tail indicating a mainly induced character of the magnetic field observed near Mars. From the fact that our study showed no distinct correlation between Martian longitude and the bow shock locations, we conclude that the Martian intrinsic magnetic dipole field is either well centralized and parallel to the Martian spin axis or so weak that it does not significantly contribute to the obstacle size under average solar wind

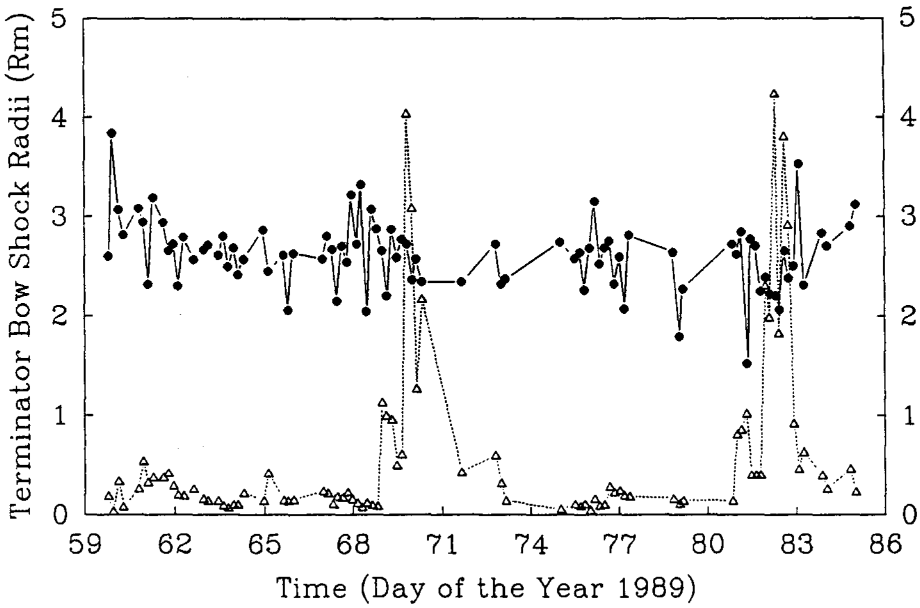

Figure 5: The Martian terminator bow shock radius (circles) and the upstream solar wind dynamic pressure (triangles, TAUS data, in arbitrary units) plotted versus the day of the year 1989.

conditions. The bow shock compressibility studies revealed only a weak dependence of the bow shock location on the upstream solar wind dynamic pressure. This does not exclude the existence of an intrinsic field, but it must be very small and might be only effective at a very low altitude and under very low solar wind dynamic pressure conditions.

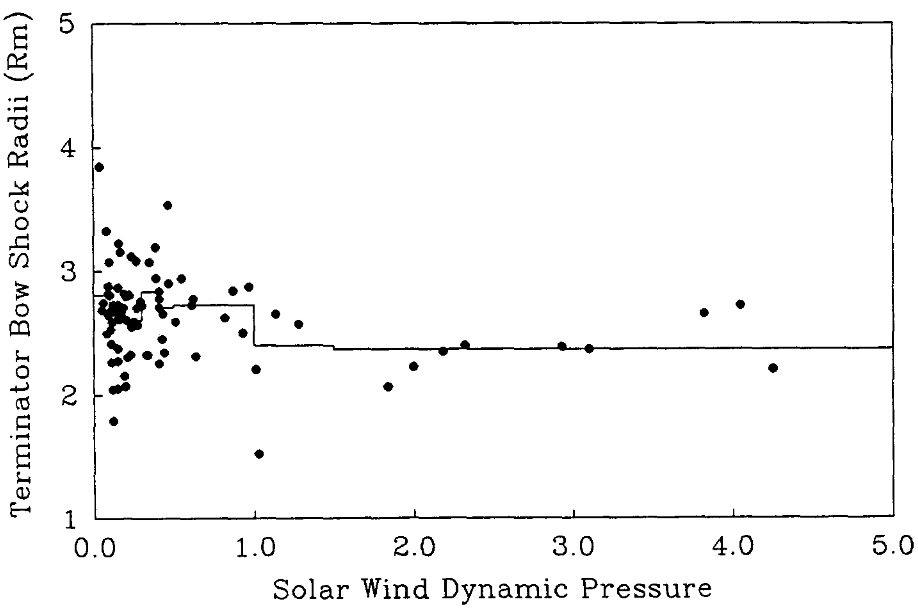

Figure 6: Scatterplot of the terminator radius versus the solar wind dynamic pressure (TAUS data). The full lines indicate medians.

ACKNOWLEDGMENTS

The authors thank Dr. M. Delva for providing the Martian geographic longitude.

REFERENCES

1. M. Dryer, and G.R. Heckman, Application of the hypersonic analog to the standing shock of Mars, *Solar Phys., 2*, 112–124, 1967.
2. K.I. Gringauz, et al., Results of solar electron plasma observations on Mars-2 and -3 spacecraft, *J. Geophys. Res., 78*, 5808, 1973.
3. O.L. Vaisberg, et al., Solar plasma interaction with Mars: Preliminary results, *Icarus, 18*, 18, 1973.
4. Sh. Sh. Dolginow, Ye. Yeroshenko and L.N. Zhuzgov, Magnetic field of Mars according to data of Mars-3 and Mars-5 satellites, *Cosmic Res., 13*, 108, 1975.
5. C. T. Russell, The magnetic field of Mars: Mars 5 evidence reexamined, *Geophys. Res. Lett., 5*, 85–88, 1978.
6. W. Riedler et al., Magnetic fields near Mars:First results, *Nature, 341*, 604–607, 1989.
7. H. Rosenbauer et al., Ions of Martian origin and plasma sheet in the Martian magnetosphere: Initial results of the TAUS experiment, *Nature, 341*, 612–614, 1989.
8. R. Lundin et al., First measurements of the ionospheric plasma escape from Mars, *Nature, 341*, 609–612, 1989.
9. N. M. Shutte et al., Observation of electron and ion fluxes in the vicinity of Mars with the HARP spectrometer, *Nature, 341*, 614–616, 1989.
10. R. Grard et al., First measurements of plasma waves near Mars, *Nature, 341*, 607–609, 1989.
11. Ye. Yeroshenko et al., The magnetotail of Mars: Phobos observations, *Geophys. Res. Lett., 17*, 885–888, 1990.
12. D. Möhlmann et al., The Question of an Internal Martian Magnetic Field, Planetary and Space Sc., in press (1990).
13. D. Möhlmann et al., Magnetic Field Environment of Mars as studied by Phobos-2, COSPAR XXVIII, this issue.
14. K. Schwingenschuh et al., Martian bow shock: PHOBOS observations, *Geophys. Res. Lett. 17*, 889–892, 1990.
15. T–L. Zhang, J. G. Luhmann and C. T. Russell, The solar cycle dependence of the location and shape of the Venus bow shock, *J. Geophys. Res., 95*, 14961–14967, 1990.
16. D. H. Fairfield, Average and unusual locations of the earth's magnetopause and bow shock, *J. Geophys. Res., 76*, 6700–6716, 1971.
17. C. T. Russell et al., Solar and interplanetary control of the location of the Venus bow shock, *J. Geophys. Res., 93*, 5461–5469, 1988.
18. J. A. Slavin, and R. E. Holzer, The solar wind interaction with Mars revisted, *J. Geophys. Res., 87*, 10285–10296, 1982.