X-690-75-322
PREPRINT

NASA TM X-71048

OBSERVATIONS OF MERCURY'S MAGNETIC FIELD

(NASA-TM-X-71048) OBSERVATIONS OF MERCURY'S MAGNETIC FIELD (NASA) 29 p HC $4.00 CSCL 03B
N76-17003
Unclas
G3/91 13246

N. F. NESS
K. W. BEHANNON
R. P. LEPPING
Y. C. WHANG

OCTOBER 1975

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

OBSERVATIONS OF MERCURY'S MAGNETIC FIELD*

by

N. F. Ness
K. W. Behannon
R. P. Lepping
Y. C. Whang**
Laboratory for Extraterrestrial Physics
NASA-Goddard Space Flight Center
Greenbelt, Maryland 20771

**Catholic University of America
Washington, D.C.

October 1975

*Presented at 1st International Colloquium on Mercury JPL/CALTECH
June 1975

Submitted to Icarus

OBSERVATIONS OF MERCURY'S MAGNETIC FIELD

ABSTRACT

This paper presents a study of magnetic field data obtained by Mariner 10 during the third and final encounter with the planet Mercury on 16 March 1975. A well developed bow shock and modest magnetosphere, previously observed at first encounter on 29 March 1974, were again observed. In addition, a much stronger magnetic field near closest approach, 400γ versus 98γ, was observed at an altitude of 327 km and approximately 70° north Mercurian latitude. Spherical harmonic analysis of the data provide an estimate of the centered planetar, magnetic dipole of 4.7×10^{22} Gauss/cm^3 with the axis tilted 12° to the rotation axis and in the same sense as Earth's. The interplanetary field was sufficiently different between first and third encounters that in addition to the very large field magnitude observed it argues strongly against a complex induction process generating the observed planetary field. While a possibility exists that Mercury possesses a remanent field due to magnetization early in its formation, a present day active dynamo seems to be a more likely candidate for its origin. The existence of such a dynamo argues for a mature planetary interior with a well developed core.

INTRODUCTION

Prior to the Mariner 10 first close flyby of Mercury on 29 March 1974, there were no indications that the planet possessed a magnetic field. The slow rotation rate, the similarity of its surface optical properties to those of the Moon and the lack of non-thermal radio emission, all suggested that Mercury would most probably be like the Moon with a negligible global planetary magnetic field. The expected characteristics of the solar wind interaction with the planet were less clear because of the uncertainty associated with the possible presence of a thin atmosphere (Ness and Whang, 1971; Banks et al., 1970).

The solar wind is an ionized, electrically neutral gas accelerated into interplanetary space (escaping the solar gravity field) by the high temperatures of the solar corona. This nearly radial plasma flow also extends the solar magnetic field into interplanetary space, whose directional characteristics are dominated by solar rotation in configuring the average field line geometry into Archimedian spirals. The velocity of this flow is well above characteristic wave speeds, such as the magnetoacoustic mode, and so it is described as supersonic. In addition, beyond a few tenths of an AU from the Sun, the solar wind is described as being collisionless, because the density is so low that classical scale lengths of particle-particle interactions are on the order of 1 AU.

As this collisionless, magnetized supersonic flow interacts with a large obstacle, such as the Earth's magnetic field, a detached bow shock develops which is analogous to the shock wave surrounding a missile reentering the Earth's ionosphere. This bow shock is easily identified by an abrupt increase in field magnitude and an increase in the fluctuations of the magnetic field. The interaction of the solar wind should also be viewed as confining the planetary magnetic field to a region of space which is termed the magnetosphere. Its boundary, the magnetopause, is well distinguished by an abrupt directional change in the magnetic field and also is reflected in the termination of higher frequency fluctuations. Thus the region between the bow shock and the magnetopause, called the magnetosheath, can be thought of as a somewhat turbulent, thick, boundary layer separating the distorted planetary magnetic field from the interplanetary medium.

One of the most unexpected discoveries of the Mariner 10 first encounter was the observation in the magnetic field data of a very well developed, strong, detached bow shock wave encompassing the planet. This was interpreted (Ness et al., 1974b; 1975a) as being due to the deflection of the solar wind around a modest-sized magnetosphere-like region associated with an intrinsic magnetic field of the planet. Supporting the interpretation of a magnetic barrier to the solar wind flow were the measurements of the low energy electron flux by Ogilvie et al. (1974), which provided strong correlative evidence for this interpretation with simultaneous identification of characteristic bow shock and magnetopause crossings. Also, intense bursts of high energy electrons and protons were reported by Simpson et al. (1974, 1975), which occurred in the magnetosphere and magnetosheath. The simultaneous observation of the protons has recently been questioned by Armstrong et al. (1975) but there is no such question regarding the fluxes of electrons (E_e > 179 Kev). It should be noted that the lack of evidence for any substantial atmosphere or ionosphere

(Broadfoot et al., 1974) clearly indicates that the interaction is quite unlike that at Venus (Ness et al., 1974, Bridge et al., 1974) where an appreciable atmosphere-ionosphere is responsible for the deflection of the solar wind flow and the development of a detached bow shock wave.

Due to the nearly exact commensurability of the heliocentric orbital period of Mariner 10 (176 days) with the orbital period of Mercury (88 days), additional encounters were possible and second and third encounters were achieved. However, the limited supply of attitude control and thruster gas precluded any further encounters and indeed restricted the operation of the spacecraft during the cruise between first to second and second to third encounters. The second encounter on 21 September 1974 was selected to obtain superior imaging coverage of the south polar regions and the spacecraft-planet miss distance was ≈ 50,000 km on the dayside. This did not permit observing directly the magnetic field of the planet or the bow shock wave associated with the solar wind interaction.

The third encounter on 16 March 1975 provided additional direct observations of the magnetic field as well as the solar wind interaction, and these data (Ness et al., 1975a; Hartle et al., 1975) dramatically confirmed the earlier interpretations of an intrinsic planetary field. It is the purpose of this paper to discuss in more detail the magnetic field observations obtained during the third encounter of Mariner 10 with the planet Mercury and the implications of an intrinsic field regarding the planetary interior. The trajectory for the third encounter was carefully selected so as to occur at a higher latitude than the near equatorial pass of the first encounter and with a closer miss distance, only 327 km relative to the first encounter miss distance of 705 km. These changes combined to provide a much more definitive sampling of the magnetic field of the planet and very complimentary observations of the bow shock and magnetopause surfaces. Both the first and third encounter trajectories were on the nightside of the planet, to optimize the opportunity to measure the planetary magnetic field and solar wind interaction region.

OBSERVATIONS

The magnetic field and solar wind electron data from the first encounter revealed the presence of the characteristic bow shock and magnetosheath and magnetosphere regions surrounding the planet Mercury. The position of the bow shock and magnetopause traversals were such that the stagnation point distance of solar wind flow was estimated to be approximately 1.6 R_M(1 R_M = 2439 km). Since in the case of the Earth, the stagnation point distance is approximately 11 R_e (1 R_e = 6378 km), it is evident that Mercury's magnetosphere is much smaller, on a relative scale (as well as absolute), and the planet Mercury occupies a much larger portion of its magnetosphere than does Earth. The results of the first encounter data, i.e., the deduced quantitative intrinsic field characteristics, will be discussed subsequently in connection with the analysis of the third encounter data.

Magnetic field observations from the third encounter are shown in Figure 1. As the spacecraft approached the planet it was observed that associated with the change in direction of the interplanetary magnetic field at 2213 UT, the magnetic field began to fluctuate with an increasing magnitude until 2222 UT. The fluctuations are measured by the Pythagorean mean of the component fluctuations, (RMS), an invariant of coordinate systems and, hence, an unambiguous measure of the fluctuations of the magnetic field. These fluctuations are identified as upstream waves due to the disturbance in the solar wind created by the bow shock.

The identification of the bow shock crossings on the inbound trajectory is not as clear as those outbound, because of the direction of the interplanetary magnetic field relative to the bow shock surface. When the interplanetary field is nearly perpendicular to the bow shock surface, or equivalently parallel to the bow shock surface normal, certain wave modes in the collisionless magnetized plasma have phase and group velocities which permit them to propagate upstream in spite of the average supersonic flow of the plasma past the obstacle. This leads to a more diffuse "boundary" and the identification of the bow shock is accomplished by close inspection of the spectral characteristics of the magnetic field fluctuations. This is possible using the high-time-resolution of the magnetic field experiment on Mariner 10 (25 vector samples per sec). For a complete discussion of the instrument, its accuracy and sensitivity, see Ness et al. (1974a).

The identification of the inbound magnetopause is straightforward, as a directional change of the magnetic field and a cessation of fluctuations is readily evident around 2230 UT. Note that five traversals of the magnetopause were identified in the higher time resolution data. (Multiple crossings of a bow shock are also common). Subsequently, the observed magnetic field increases in magnitude to a maximum of 400γ very near closest approach to t. planet. Note the steady variation in the direction of the magnetic field as measured by the latitude and longitude parameters, θ and ϕ. The sense of the field is primarily toward the planet with a smooth variation from westward to eastward.

The outbound crossing of the magnetopause is identified near 2244 UT by the sudden, brief decrease in the magnitude at the same time as the fluctuations increase significantly. Subsequently, the identification of the first outbound crossing of the bow shock (near 2248 UT) is seen in the abrupt decrease in field magnitude as well as a decrease in fluctuations. The third (and last) outbound crossing occurs at about 2250 UT. Again, upstream waves are observed.

Simultaneous observations of the solar wind electrons by Hartle et al. (1975a) provided confirmatory evidence for the identification of the position and nature of the bow shock and magnetopause crossings as well as more definitive information on the characteristics of the plasma within the Hermean magnetosphere. Both magnetic field and solar wind electron observations obtained by Mariner 10 show a good correspondence to the Earth's magnetosphere. However, as mentioned previously, Mercury occupies a larger fraction of its magnetosphere than Earth by about a factor of 7 ($\approx 11/1.6$). Thus, even when measurements are performed relatively close to the surface of Mercury, the net magnetic field includes a substantial contribution due to external sources associated with the deflected solar wind flow.

It is this fact, coupled with a small data set available in the limited volume of the magnetosphere sampled by Mariner 10, which restricts our ability to analyze the data uniquely in quantitative terms and to describe the characteristics of an internal planetary magnetic field. The joint plasma, charged particle (Simpson et al, 1974) and magnetic field data sets do establish, with little doubt, that the origin of the magnetic field is intrinsic to the planet rather than associated with an induction process due to the flow of solar wind.

ANALYSIS

The quantitative characteristics of the intrinsic field derived from Mercury I and Mercury III encounter data are quite similar, in spite of a substantial change in the orientation of the interplanetary magnetic field. If the magnetic field were created by a steady induction process due to the solar wind flow, then one would expect a corresponding change in the planetary field characteristics associated with the change in the interplanetary magnetic field and solar wind flow. Also, the magnitude of the field observed at Mercury III reaches a maximum value of 400γ, a factor of 20 larger than the average interplanetary field at the time of observation. It is presently not possible to construct any induction process which would lead to such an amplification factor (Sonett, 1975).

Traditionally, the magnetic field of the Earth has been analyzed in terms of harmonic multipoles. The simple, first approximation approach used here has been to assume internal sources described by an harmonic term of degree of 1. This means a centered dipole whose tilt, phase and magnitude will be determined by the data. Contributions from sources external to the planet are assumed to be approximated sufficiently well by a uniform field whose direction and magnitude will also be determined.

A least squares fit of the data has been made by the classical minimization process for the field components. The results obtained for the internal dipole coefficients for Mercury I and Mercury III encounters for different data subsets are shown in Table I.

From the harmonic coefficients, it is found that the internal magnetic field of the planet is well described by a centered dipole of moment 4.7×10^{22} Gauss-cm^3, oriented within 12° of the normal to the orbit plane. This magnetic moment compares very favorably with that deduced from the positions of the magnetopause and bow shock boundaries and the inferred cross-section responsible for solar wind deflection. Note that the sense of the dipole is the same as Earth's.

Included in Table I are parameters describing the distribution of data points used in the analyses and the mathematical confidence which one can place in the derived results. Different subsets of data were chosen in both encounters in order to test the sensitivity of the final result because of the lack of complete data necessary to determine uniquely the internal magnetic multipoles of the planet. Note that the condition number, which measures the stability of the analysis, is better (significantly lower) for the third encounter. This is due to both the trajectory as well as a more simplified external magnetic field assumed in the analysis.

A graphical presentation of the data, which illustrates clearly its characteristics relative to the planet, is shown in Figure 2. This diagram presents two views of the trajectory and measured magnetic field vectors within the magnetosphere: from the sun and from the north ecliptic pole. Note the correlated, steady directional change and field magnitude variation as the spacecraft traverses the magnetosphere. Also illustrated is the direction of the interplanetary magnetic field relative to the bow shock during inbound and outbound crossings.

The goodness of fit, as measured by the RMS parameter, appears to be somewhat poorer for the third encounter. This is due primarily to the wide range of large field values encompassed by the magnetosphere data and the low order field model used. The data fit is illustrated graphically in Figure 3 by comparing the three orthogonal components of the observed magnetic field within the magnetosphere to those computed from the theoretical model. It is seen that the data-fitting interval is confined to a period near closest approach when the field magnitude is always larger than 100γ. The data fits show the largest deviation in the Z component (north-south) near the boundaries of the magnetosphere.

The magnetic field intensity on the surface of Mercury due to the centered dipole would be $\sim$350γ at the equator and increase to $\sim$700γ at the poles. However, there is a significant distortion of this field due to the external sources. The data fit for Mercury III gives an external field, assumed uniform along the trajectory, of

$$X = -27 \text{ to } -17\gamma$$

$$Y = -8 \text{ to } 4\gamma$$

$$Z = -53 \text{ to } -30\gamma$$

for data subsets 1 and 2 respectively (in Mercury ecliptic coordinates).

It cannot be assumed with confidence that this field represents accurately the external contributions on the surface of the planet. But it does provide a guide which suggests that field intensities on the surface will be between about 300 and 800γ. Of course, variations in the solar wind flux will change the size of the magnetosphere and hence the magnetopause location; this will vary the contribution of electrical currents flowing on the magnetopause, so we may expect surface fields from a few hundred gamma up to one thousand gamma.

INTERPRETATION

The existence of a modest magnetic field at Mercury sufficient to deflect the solar wind flow implies that there should exist a magnetic tail and an embedded neutral sheet similar to Earth's. It is probably this neutral sheet and its time fluctuations (Siscoe et al., 1975) which were responsible for the acceleration of the charged particles observed by Simpson et al. (1974). The modest size of the magnetosphere means that while a major fraction of the solar wind is deflected around the planet, a small but significant fraction of the incident solar wind can enter the magnetosphere. As Hartle et al. (1975b) have shown, this can readily explain the observed thin helium exosphere. The entry is most probably through the polar cap regions, both of which can be more sunward on Mercury than on Earth, as well as in the neutral sheet of the magnetic tail. This flux will also impact the surface, in the absence of an atmosphere, and alter its optical properties in similar fashion to lunar materials.

The orbit of Mercury is modestly eccentric and the solar wind intensity is known to vary with time. Taking these factors into account, and using extended observations of the solar wind at 1 AU, Siscoe and Christopher (1975) have shown that the magnetic field of Mercury is sufficiently strong that the solar wind should be deflected around the planet most of the time. This conclusion, based upon present day observations of the annual variation of solar wind flux, cannot be extrapolated to an earlier stage of formation of the solar system. Then the solar wind intensity was much higher and the planetary surface was probably not protected from direct impact by the solar wind.

A fundamental question which cannot be answered at this time is the origin of this global, intrinsic planetary field. As previously mentioned, the data do not support theories which invoke a complex induction process associated with the flow of the solar wind. The most plausible explanations of the observed field are:

1. A present day active internal dynamo such as on Earth, see the review by Gubbins (1974) and/or
2. Fossil magnetization after cooling.

Both sources depend upon the thermal history of the planetary interior. It is not possible to distinguish between the two mechanisms from the available magnetic data. If definitive measurements of the planetary magnetic field were possible over an extended time period, then secular changes such as is observed on the Earth, would be strong evidence for an active dynamo. The available measurements are unfortunately neither separated in time sufficiently far nor sufficiently precise to permit use of the two different encounter data sets to attempt an answer to this question.

Due to the high average density of the planet, 5.44 gms/cm ^{3}, it is fairly certain that Mercury contains a large amount of iron and nickel, on the order of 60%. This is most probably concentrated in a large core (Siegfried and Solomon, 1974; Toksoz and Johnston, 1974). If such a core were at low temperatures, below the Curie point, then a remanent magnetic field would be plausible. But the problem would be to determine the origin of the magnetizing field, if it were not primordial.

However, the possibility of a sufficiently cold interior seems rather remote in the light of studies on the thermal evolution of the terrestrial planets. Toksoz and Johnston (1974) and Siegfried and Solomon (1974) have shown that early in Mercury's history an iron nickel core probably formed, whose radius at present is approximately 1600 km. Such a large core can support a planetary dynamo, if the appropriate combination of fluid motions and electrical properties exists. The slow rotation of the planet is not an impediment to the successful application of dynamo theory (Busse, 1975), since important relevant physical parameters in the dynamo are not accurately known. These include flattening, differential rotation of the planetary interior, magnetic Reynolds number and other such quantities. Whether the dynamo is driven by precessional torques, as recently suggested by Dolginov (1975), or by thermal convection due to heat released by radioisotope decay will not be determinable from any set of magnetic field data.

The validity of precessionally driven dynamos has recently been questioned by Rochester _et al._ (1975) for Earth, and thus it may be less probable that a similar process can occur at Mercury. It should be noted that all of the critical physical parameters describing Mercury are much less well known than they are for Earth, and an adequate, fully quantitative theory for the generation of its magnetic field has yet to be developed.

If fossil magnetization is the source of the field, then a wide range of possible source region characteristics exists. The simplest configuration is that of a uniformally magnetized, thin, spherical shell. The magnetization required for such a shell to explain the observed magnetic moment is not much larger than the remanent magnetizations found in returned lunar samples (Fuller, 1974). With a lithospheric shell below the Curie point, whose thickness is 20% of the radius (488 km), the necessary magnetization is 3.1×10^{-4} emu/gm. Were the shell 10% thick, i.e., 244 km, the value rises to 5.9×10^{-4} emu/gm. This seems to be well within the range of materials which may be expected to be present on the surface of Mercury.

However, one problem which this explanation faces is the process whereby the shell becomes magnetized, uniformally or otherwise. The periodic changes in direction of the interplanetary magnetic field, as observed and as required by $\nabla\cdot B = 0$, imply that no externally generated fields can provide a net magnetizing field. Runcorn (1975), in studying the magnetization of the Moon, has suggested that if a spherical shell of a planet cooled down below the Curie point in the presence of an internally generated magnetic field, then no external field would be observed after the dynamo decays. This conclusion has been refined by Goldstein (1975), Runcorn (1975b,c) and Srnka (1975) who find that in fact a small, residual external dipole field may be present after such a dynamo has decayed.

Studies of the thermal evolution of Mercury have generally assumed two rather extreme distributions of radioisotope heat sources as limits representative of the true distribution. Shown in Figure 4 are the near-surface temperature profiles for two such models. It is seen that at present (4.6 billion years), the maximum thickness of a spherical shell, which would be below the Curie point, is 400 km. This is in the case where no core forms. In the case where a core is formed, both Siegfried and Solomon (1974) (as shown in Figure 4 b) and Toksoz and Johnston (1974) find that the maximum thickness of t · spherical shell below the Curie point is only 200 km. This thin shell cannot be plausibly magnetized uniformally nor by an internal dynamo to a sufficient level to match the required dipole moment. Thus we conclude that a fossil magnetization explanation is inadequate, based upon our present understanding of the planet Mercury and magnetization of cooling planets. This means that an active dynamo, which cannot be presently rejected, remains the most plausible explanation of the observed global magnetic field. Thus the magnetic field observations and interpretations provide a strong indication that Mercury possesses a mature differentated interior.

LIST OF FIGURES

ACKNOWLEDGEMENTS

We appreciate very much the support of our GSFC colleagues D. Howell, J. Scheifele, J. Seek and R. Thompson in the conduct of this experiment and the analysis of the data.

REFERENCES

Armstrong, T. P., Krimigis, S. M. and Lanzerotti, L. J. (1975) A reinterpretation of the reported presence of energetic proton fluxes in the vicinity of Mercury. J. Geophys. Res. 80, 4015-4017.

Banks, P. M., Johnson, H. E. and Axford, W. I. (1970) The atmosphere of Mercury. Comments Astrophys. Space Phys. 2, 214-217.

Bridge, H. S., Lazarus, A. J., Scudder, J. D., Ogilvie, K. W., Hartle, R. E., Asbridge, J. R., Bame, S. J., Feldman, W. C., and Siscoe, G. L. (1974) Observations at Venus encounter by the plasma science experiment on Mariner 10. Science 183, 1293-1997.

Broadfoot, A. L., Kumar, L. S., Belton, M. J. S. and McElroy, M. B. (1974) Mercury's atmosphere from Mariner 10. Science 185, 166-169.

Busse, F. H. (1975), private communication.

Dolginov, Sh. Sh. (1975) On the magnetic dynamo mechanism of the planets. IZMIRAN preprint N 9a (124).

Fairfield, D. H. and Behannon, K. W. (1975) Bow shock and magnetosheath waves at Mercury. J. Geophys. Res. (to appear).

Fuller, M. (1974) Lunar magnetism. Revs. Geophys. and Space Physics 12, 23-70.

Goldstein, M. L. (1975) Lunar Magnetism. Nature 258, 175.

Gubbins, D. (1974) Theories of the geomagnetic and solar dynamos. Revs. Geophys. Space Physics 12, 137-154.

Hartle, R. E., Curtis, S. A., Thomas, G. E. (1975b) Mercury's helium exosphere. J. Geophys. Res. 80, 3689-3692.

Hartle, R. E., Ogilvie, K. W., Scudder, J. D., Bridge, H. S., Siscoe, G. L., Lazarus, A. J., Vasylianas, V. M. and Yeates, C. M. (1975a)

Preliminary interpretations of plasma electron observations at the third encounter of Mariner 10 with Mercury. Nature 255, 206-208.

Ness, N. F. and Whang, Y. C. (1971) Solar wind interaction with Mercury. J. Geophys. Res. 76, 3136-3143.

Ness, N. F., Behannon, K. W., Lepping, R. P., Whang, Y. C. and Schatten, K. H. (1974a) Magnetic field observations near Venus: Preliminary results from Mariner 10. Science 183, 1301-1306.

Ness, N. F., Behannon, K. W., Lepping. R. P., Whang, Y. C. and Schatten, K. H. (1974b) Magnetic field observations near Mercury: Preliminary results. Science 185, 151-160.

Ness, N. F., Behannon, K. W., Lepping, R. P. and Whang, Y. C. (1975a) Magnetic field of Mercury confirmed. Nature 255, 204-206.

Ness, N. F., Behannon, K. W., Lepping. R. P. and Whang, Y. C. (1975b) The magnetic field of Mercury, 1.. J. Geophys. Res. 80, 2708-2716.

Ogilvie, K. W., Scudder, J. D., Hartle, R. E., Siscoe, G. L., Bridge, H. S., Lazarus, A. J., Asbridge, J. R., Bame, S. J. and Yeates, C. M. (1975) Observations at Mercury encounter by the plasma science Experiment on Mariner 10. Science 185, 145-151.

Rochester, M. G., Jacobs, J. A., Smylie, D. E. and Chang, K. F. (1975) Can precession power the geomagnetic dynamo? Geophys. J. R. Astr. Soc. 43, (to appear).

Runcorn, S. K. (1975a) An ancient lunar magnetic dipole, Nature 253, 701-703.

Runcorn, S. K. (1975b) On the interpretation of lunar magnetism. Phys. Earth Planetary Inter. 10, 327-335.

Runcorn, S. K. (1975c) Reply. Nature 258, 175-176.

Siegfried, R. W. II, and Solomon, S. C. (1974) Mercury: Internal structure and thermal evolution. Icarus 23, 192-205.

Simpson, J. A., Eraker, J. H., Lamport, J. E. and Walpole, P. H. (1974) Electrons and protons accelerated in Mercury's magnetic field. Science 185, 160-166.

Simpson, J. A. (1975) Reply J. Geophys. Res. 80, 4018.

Siscoe, G. L., Ness, N. F. and Yeates, C. M. (1975) Substorms on Mercury? J. Geophys. Res. 80, 4359-4363

Siscoe, F. L. and Christopher, L. (1975) Variations in the solar wind standoff distance at Mercury. Geophys. Res. Letters 2, 158-160.

Sonett, C. P. (1975) Paper presented at 1st Int. Colloquium on Mercury.

Srnka, L. J. (1975) Magnetic dipole moment of a spherical shell with TRM acquired in a field of internal origin. Phys. of the Earth and Planetary Interiors (to appear).

Toksoz, M. N. and Johnston, D. H. (1975) The evolution of the Moon and the terrestrial planets. In Proceedings of the Soviet-American Conference on the Moon and Planets, (in press).

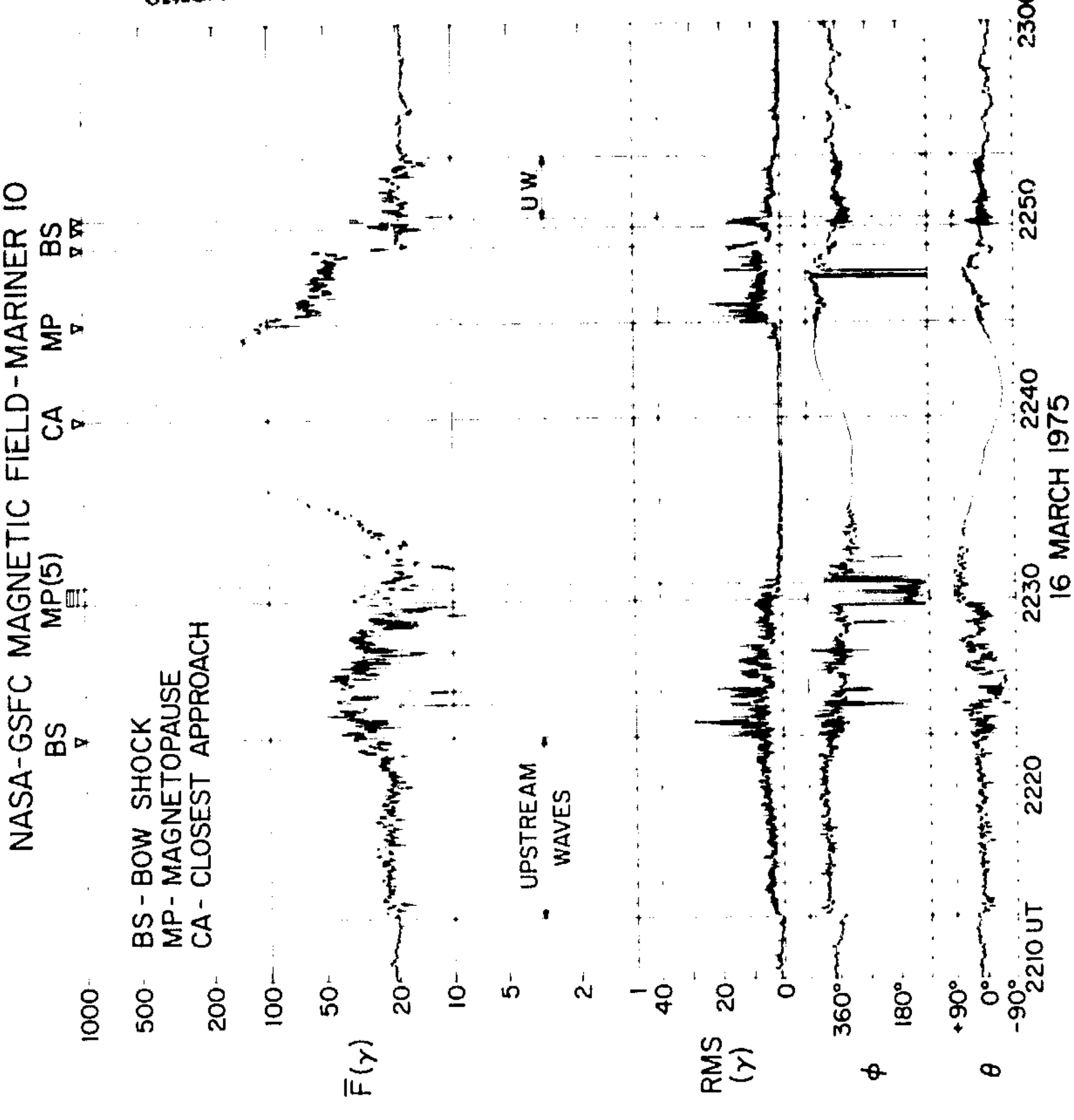

NASA-GSFC MAGNETIC FIELD-MARINER 10
BS
MP(5)
CA
MP
BS
BS - BOW SHOCK
MP - MAGNETOPAUSE
CA - CLOSEST APPROACH
UPSTREAM WAVES
U W
F̄(γ)
RMS (γ)
φ
θ
1000
500
200
100
50
20
10
5
2
1
40
20
0
360°
180°
+90°
0°
-90°
2210 UT
2220
2230
2240
2250
2300
16 MARCH 1975

FIGURE 1

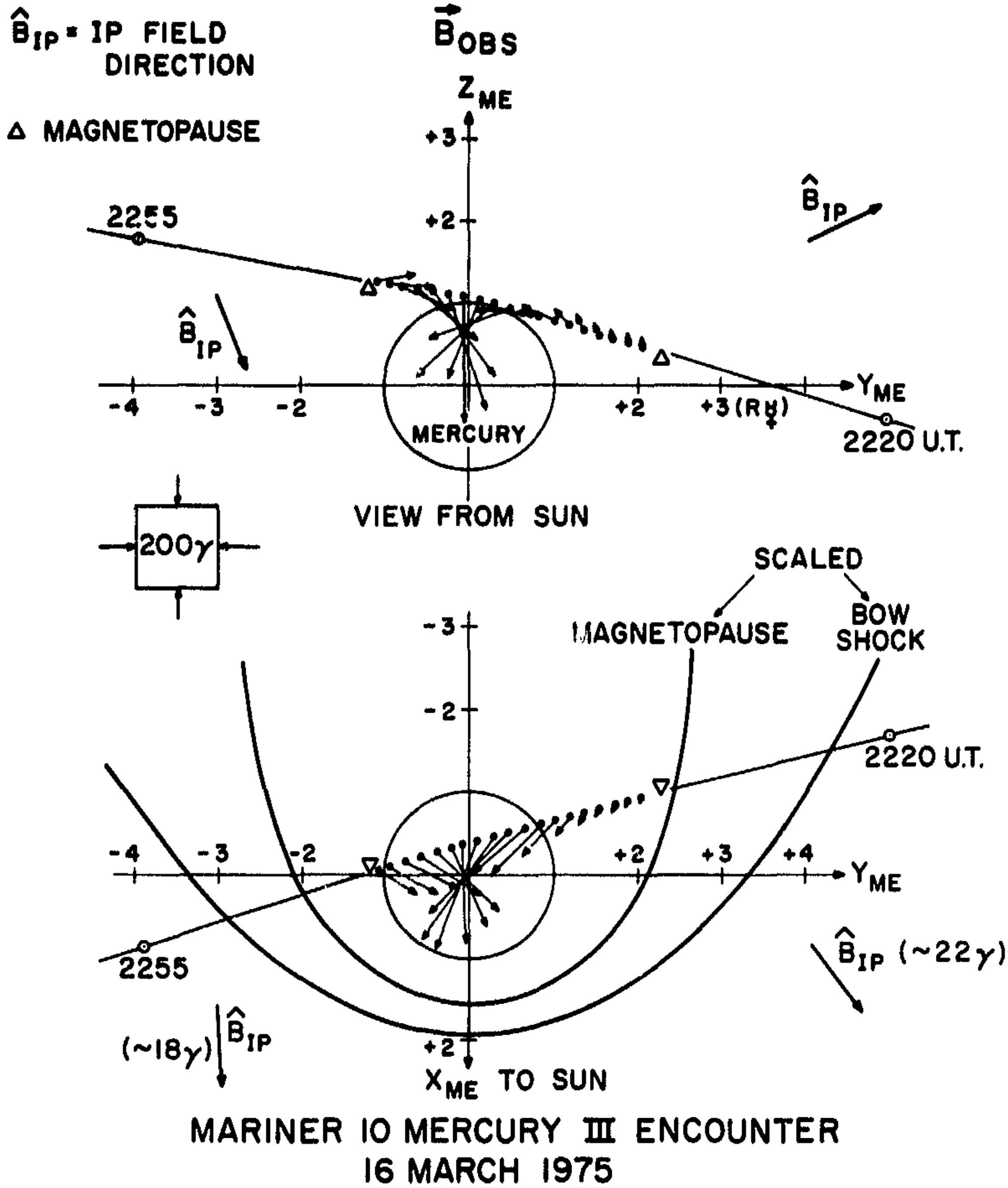

$\hat{B}_{IP}$ = IP FIELD DIRECTION
△ MAGNETOPAUSE
$\vec{B}_{OBS}$
Z_{ME}
+3
+2
2255
$\hat{B}_{IP}$
$\hat{B}_{IP}$
-4
-3
-2
+2
+3 ($R_☿$)
Y_{ME}
MERCURY
2220 U.T.
VIEW FROM SUN
200γ
SCALED
MAGNETOPAUSE
BOW SHOCK
-3
-2
2220 U.T.
-4
-3
-2
+2
+3
+4
Y_{ME}
2255
$\hat{B}_{IP}$ (~22γ)
(~18γ) $\hat{B}_{IP}$
+2
X_{ME} TO SUN
MARINER 10 MERCURY III ENCOUNTER
16 MARCH 1975

FIGURE 2

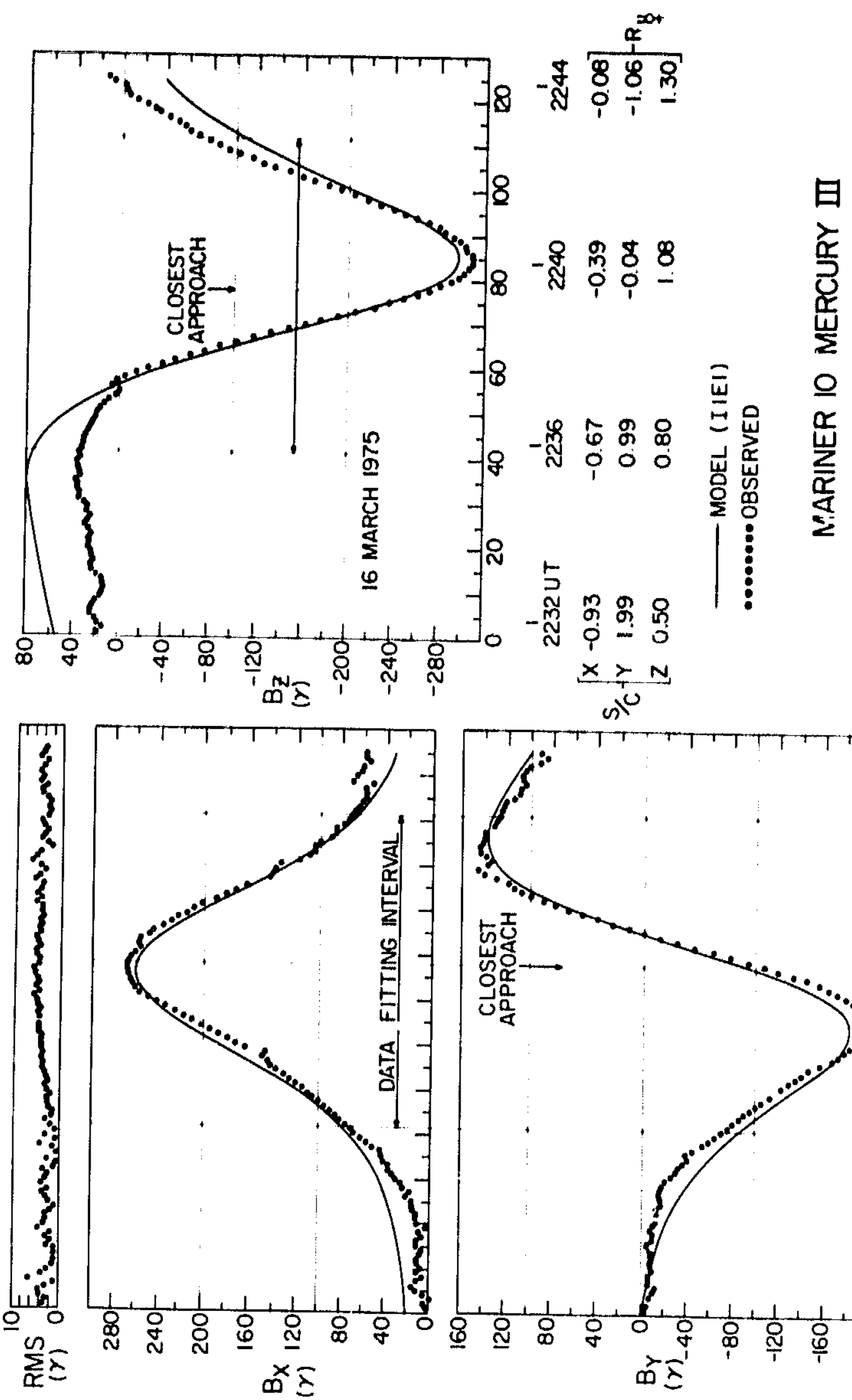
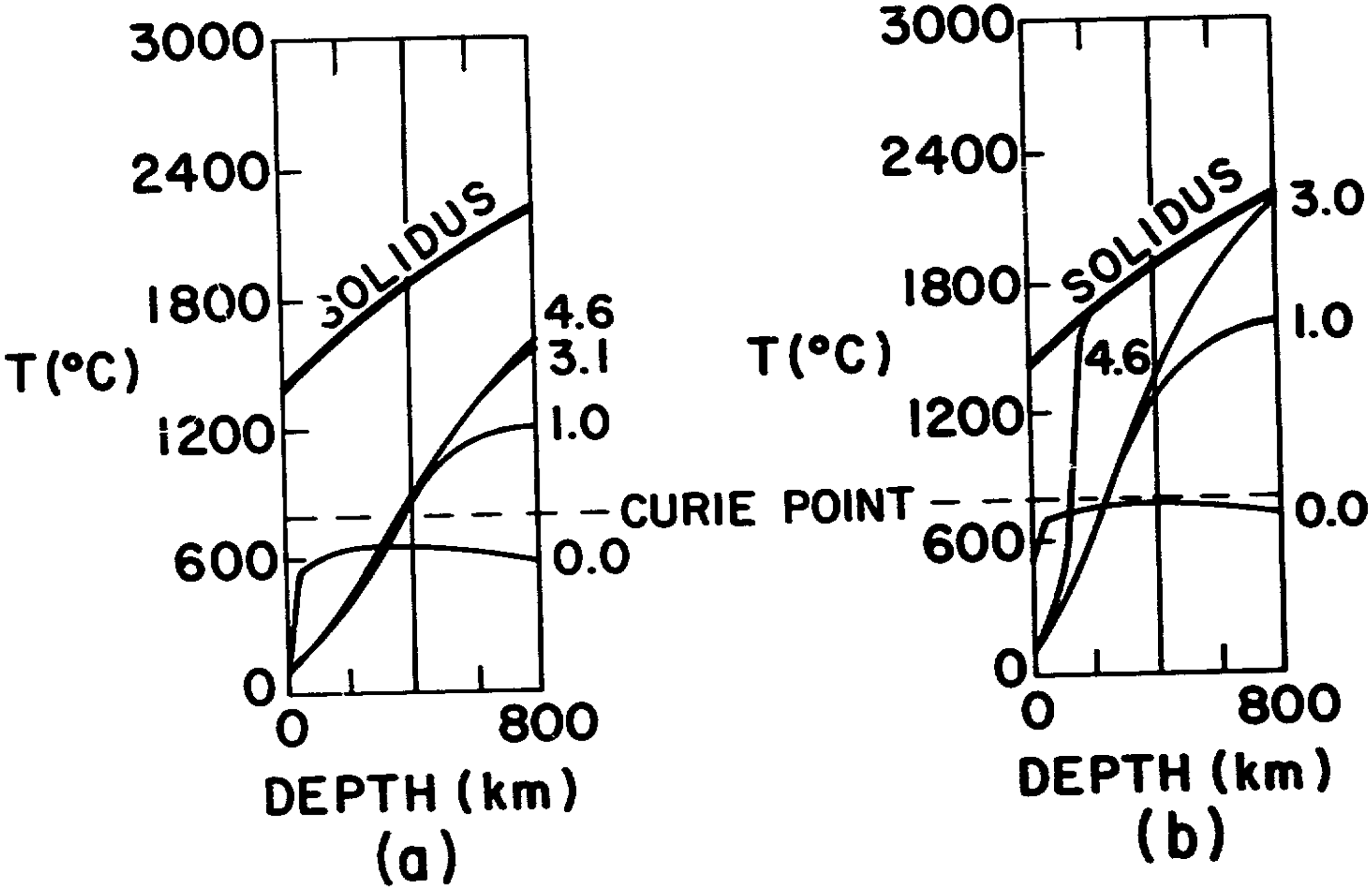

RMS (γ)
Bx (γ)
By (γ)
Bz (γ)
DATA FITTING INTERVAL
CLOSEST APPROACH
16 MARCH 1975
2232 UT
2236
2240
2244
S/C X -0.93 -0.67 -0.39 -0.08
Y 1.99 0.99 -0.04 -1.06
Z 0.50 0.80 1.08 1.30
R☿
MODEL (I I E I)
OBSERVED
MARINER 10 MERCURY III

FIGURE 3

MERCURY



ADAPTED FROM SIEGFRIED AND SOLOMON (1974)

FIGURE 4

SUMMARY OF SHA OF MERCURY 1 & 3

	1_A	1_B	3_A	3_B	UNITS
DIPOLE MOMENT	5.1×10^{22}	4.1×10^{22}	5.2×10^{22}	4.7×10^{22}	GAUSS CM^3
	(350)	(284)	(358)	(327)	$(\gamma R_M{}^3)$
LATITUDE	-80°	-83°	-79°	-78°	SOLAR ECLIPTIC
LONGITUDE	285°	289°	101°	129°	
ΔT	42	6	6	6	SECONDS
NO. PTS	10	70	60	[illegible]	N
RMS	0.9	1.7	10.6	13.8	γ
"QUALITY"	1	1.5	0.88	0.73	$3F_{MAX}\sqrt{N}\ 10^{-3}/RMS$
CONDITION NUMBER	5300	6100	15	13	
COMMENT	QUIET DATA	QUIET DATA	SUBSET 1	SUBSET 2	

8/14/75