General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NASA TM X- 71048

OBSERVATIONS OF MERCURY'S MAGNETIC FIELD

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

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 distin-
guished 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

6

(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 .n 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., 1) .. 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 2048 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 induc-

tion 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 ass d 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 computel
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 $\sim350\gamma$ at the equator and increase to $\sim700\gamma$ 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 differen' 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 L · 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 under-

standing 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

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.

Sruka, 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).

FIGURE 1

$\hat{B}_{IP}$ = IP FIELD DIRECTION

△ MAGNETOPAUSE

$\vec{B}_{OBS}$

VIEW FROM SUN

SCALED MAGNETOPAUSE

BOW SHOCK

MARINER 10 MERCURY III ENCOUNTER
16 MARCH 1975

FIGURE 2

FIGURE 3

MERCURY

T(°C) — DEPTH (km)

(a) (b)

CURIE POINT

SOLIDUS
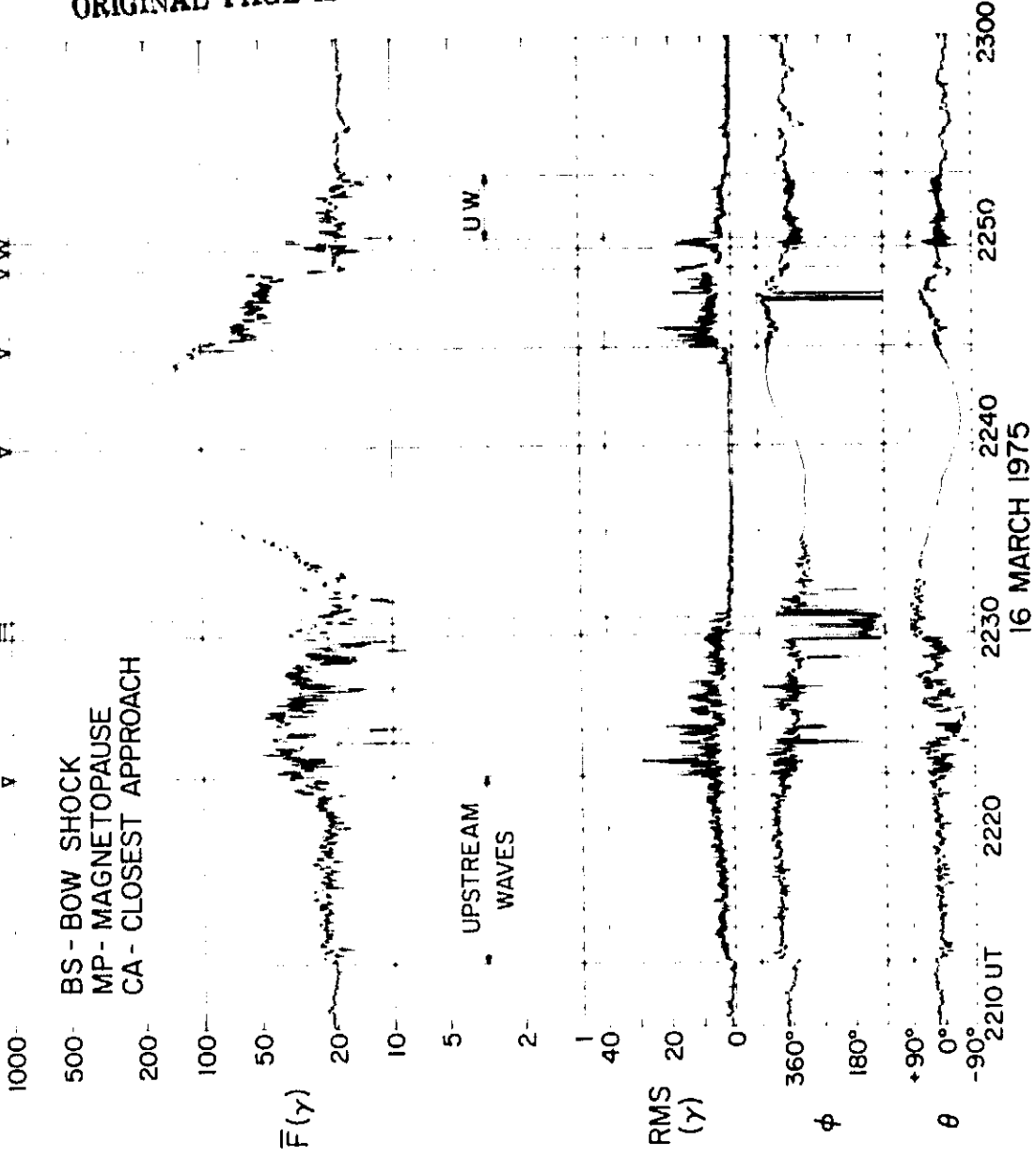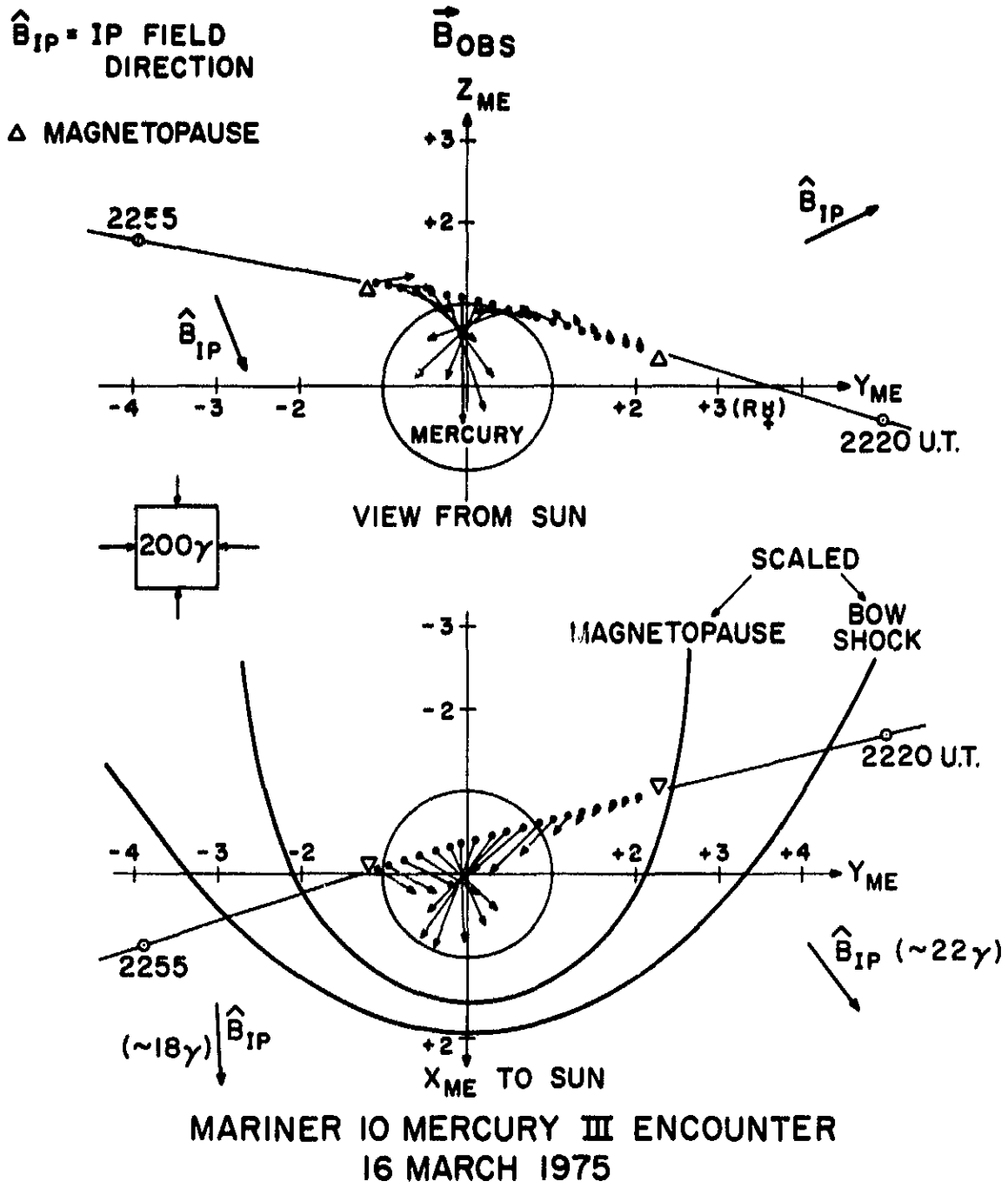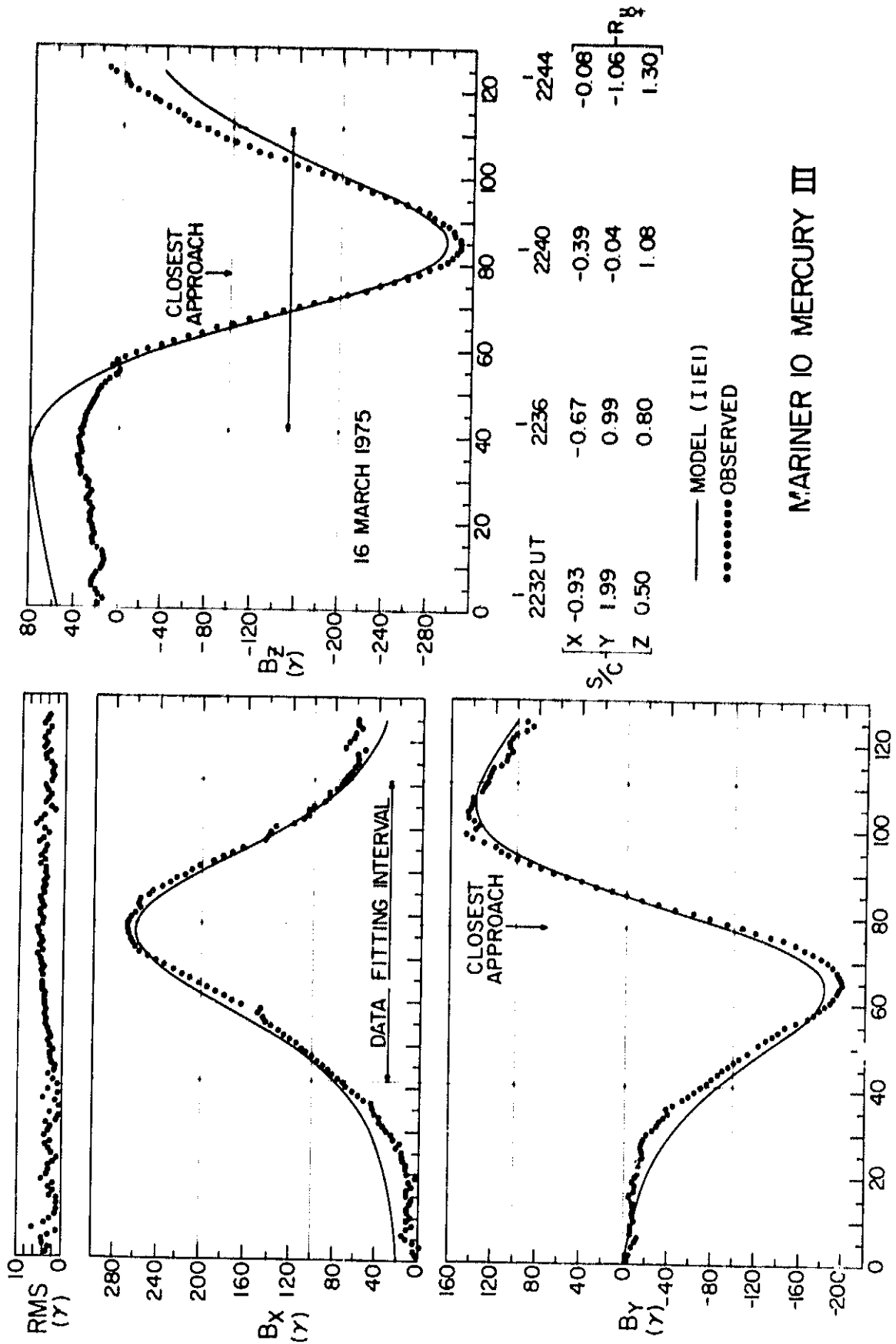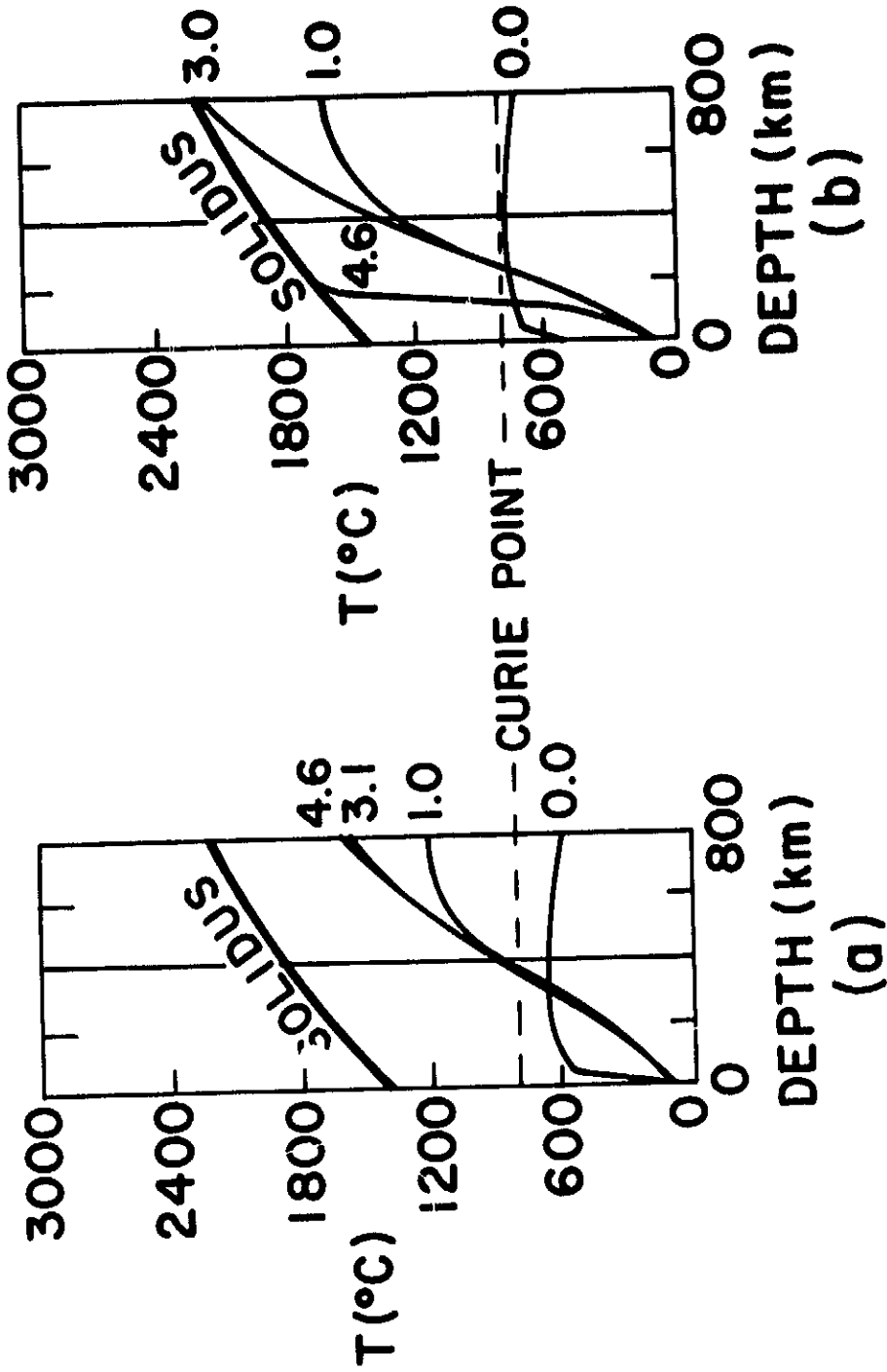
ADAPTED FROM SIEGFRIED AND SOLOMON (1974)

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)	(γR_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	.0	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