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MAGNETIC FIELD OF MERCURY CONFIRMED

by

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On 16 March 1975, the USA Spacecraft Mariner 10 achieved its third and final encounter with the planet Mercury. This unique and fortuitous event occurred because the heliocentric orbital period of Mariner 10 was 176 days, exactly twice that of the orbital period of Mercury, 88 days. The principal objective of the third flyby was to confirm or reject the suggestion from the first flyby on 29 March 1974 that Mercury may possess a modest intrinsic magnetic field sufficient to deflect the solar wind flow[1-2]. The quantitative analysis[3] of the Mercury I data yielded an estimate of the planetary magnetic dipole moment equal to 5.1×10^{22} Gauss cm^3 and oriented 7^o from the orbit normal. The spacecraft was severely limited in its ability to function properly since Mercury I due to various technical failures. However, a dedicated effort by the spacecraft engineering team at NASA/JPL achieved the desired objective at Mercury III of a very close darkside pass at the planet. This letter presents preliminary results from the NASA/GSFC magnetometer instrumentation on Mariner 10.

The flyby trajectory is shown in planetary centered solar ecliptic coordinates in Figure 1. This is a preliminary trajectory and will be updated with post encounter tracking observations when they have been analyzed. The nominal miss distance at closest approach was approximately 323 ± 8 km. For comparison, also shown in Figure 1 is the trajectory at Mercury I encounter, for which the closest approach miss distance was $\approx$ 704 km. In the right panel, showing the view from the Sun, the much higher latitude pass of the spacecraft during Mercury III is well illustrated. This closer and more poleward targeting was chosen so as to yield magnetic field measurements which would provide unequivocal evidence regarding the nature of the planetary magnetic field at Mercury. The Mercury I results were consistent with a reduced scale model of the solar wind interaction with the terrestrial magnetic field, in which the planetary field is compressed by the solar wind flow, which itself is deflected around the planet, and a detached bow shock wave forms. As a result, the field is then confined to a region of space close to the planet on the Sunward side and extended to form a magnetic tail on the nightside.

Based upon the observations and analysis at Mercury I and assuming similar conditions of solar wind momentum flux at Mercury III, predictions were made of the locations where the characteristic bow shock and magnetopause boundaries would be observed. The position of these boundary surfaces is presented in the left panel of Figure 1. Since the rotation period of the planet is uniquely coupled to its orbital period, in the ratio 2:3, the "phase" of the planet relative to the planet-Sun line at successive encounters was identical.

The observed positions of the bow shock and magnetopause during Mercury III are also illustrated in Figure 1. They show excellent agreement with the model boundaries, which used a scaling of the magnetic moment of Mercury equal to 7×10^{-4} that of the Earth's dipole moment. In the case of the solar wind flux impinging normal to a dipole field, a theoretical study[4] has yielded the relationship $\frac{R_{mp}}{R_p} = 1.07 \left[\frac{B_o^2}{4\pi mnV^2}\right]^{1/6}$ where R_{mp}/R_p = the normalized radius of the stagnation point distance of the magnetopause, B_o = equatorial dipole field intensity, and nmV^2 = solar wind momentum flux (where n = number density, m = mass of proton and V = velocity of solar wind). The distance to the magnetopause, as measured by R_{mp} is thus weakly dependent upon solar wind momentum flux and hence even if variations of ±60% in the solar wind flux occur, they would alter the position of the characteristic bow shock and magnetopause boundaries by only ±10%.

The magnetic field measurements were accomplished with a dual magnetometer[5] system which sampled the vector magnetic field 25 times each second, with a precision of ±.125γ for each orthogonal component. These data are to be considered preliminary in that they are accurate to ±1-2γ or ±1%, which ever is larger, because they are derived from quick look data provided in near real time by JPL. Six second averages of the observed magnetic field throughout the encounter period are shown in Figure 2. The occurrence of the well developed bow shock and magnetopause boundaries are indicated and readily identified by a magnitude and/or directional change as well as in the Pythagorean mean fluctuation characteristic, RMS. The maximum magnitude of the field is 400γ, 4 times larger than that observed at Mercury I encounter and 20 times larger than the interplanetary field, which is close to 20γ. This large value precludes any reasonable possibility that the magnetic barrier to solar wind flow is associated with a complex induction process occurring at the planet. The direction of the magnetic field, as measured by latitude θ and longitude ϕ, is primarily towards the Sun (and planet) with gradual changes along the trajectory within the magnetosphere boundaries. This orientation is opposite to that observed at Mercury I encounter but is perfectly consistent with the model of a Mercurian magnetosphere[6] in which the planetary field is represented by a centered dipole normal to the solar wind flow and which is then highly distorted by magnetopause currents.

A preliminary spherical harmonic analysis of the data within the magnetosphere has been conducted using the available trajectory. The analysis assumes a centered planetary dipole field, i.e., harmonic order N = 1, as well as external field sources described by harmonic terms up to order N = 2. The preliminary least squares fit yields a residual of 7γ with the deduced parameters for the planetary dipole listed in Table I. These are compared with those values derived from Mercury I and are seen to be in remarkably good agreement, considering the preliminary nature of these results. The magnitude of the dipole moment is the same within 10% and its direction only 24° from that derived earlier. The uncertainty associated with the present analysis precludes attributing any significance to these small differences.

In summary, the observations at the third encounter with Mercury by the NASA/GSFC magnetic field experiment have dramatically confirmed the earlier tentative conclusion that Mercury possesses a modest magnetic field intrinsic to the planet. The origin of this magnetic field is at present uncertain. It may be associated with remanent magnetization of portions of the planet, i.e., material presently below its Curie point, or it may be due to an active dynamo in the presumably large iron/nickel core. It is difficult to construct a plausible sequence of events leading to the model in which the Mercurian magnetic field is due to remanent magnetization. Thus, we conclude tentatively that these observations of an intrinsic magnetic field require the existence of an active dynamo mechanism in the interior of the planet. Future detailed and final studies of the Mercury III encounter results and intercomparison with those from Mercury I encounter, as well as considerations of possible interior structures, should yield significant insight into the present physical state of Mercury.

We express sincere appreciation to Dr. James Dunne, JPL Project Scientist on Mariner 10, and the JPL spacecraft team for their outstanding effort in achieving the third encounter. We also appreciate the special efforts of D. H. Howell, F. W. Ottens and R. F. Thompson of the NASA/GSFC for their special efforts and prompt analysis of these data

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Table I

Comparison of Planetary Dipole Moments Obtained by Spherical Harmonic Analysis of Magnetic Field Data

	Mercury I 29 March 1975	Mercury III 16 March 1975
Dipole Moment (Gauss cm^3)	5.1×10^{22} ($350\gamma\ R_m^3$)	$4.8(\pm.5) \times 10^{22}$ ($330 \pm 30\gamma\ R_m^3$
Latitude (ME coordinates)	-80°	$-76^\circ \pm 5^\circ$
Longitude (ME coordinates)	285°	$90 \pm 30^\circ$
Root Mean Square Residual	0.9γ	7γ
Comment	(Quiet Data Only)	(Preliminary but entire data set)

List of Figures

Figure 1 Mariner 10 spacecraft trajectory in Mercury centered solar ecliptic coordinates. The left panel plots the trajectory as distance, X_{SE}, from the dawn-dusk terminator of the planet, versus distance from the planet-Sun line, $\left[Y^2 + Z^2\right]^{1/2}$. The right panel presents the view from the Sun with Z_{SE} positive to north ecliptic pole.

Figure 2 Measurements by the NASA/GSFC Magnetometer on Mariner 10 during Mercury III encounter. Magnetic field direction latitude, θ, is referenced with respect to a plane parallel to the ecliptic and longitude, ϕ, with respect to the planet-Sun line reckoned positive relative towards the east limb of the Sun.

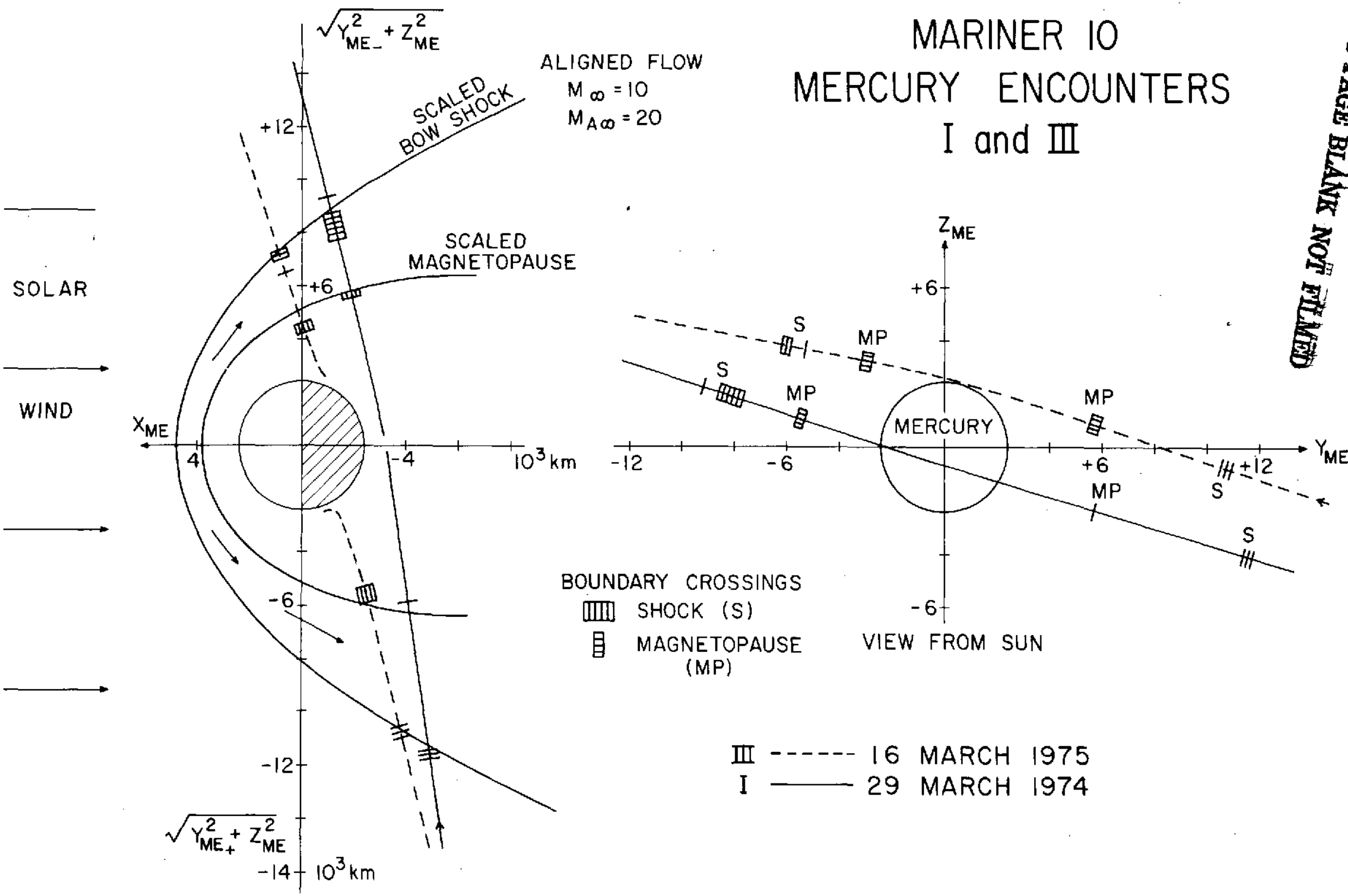
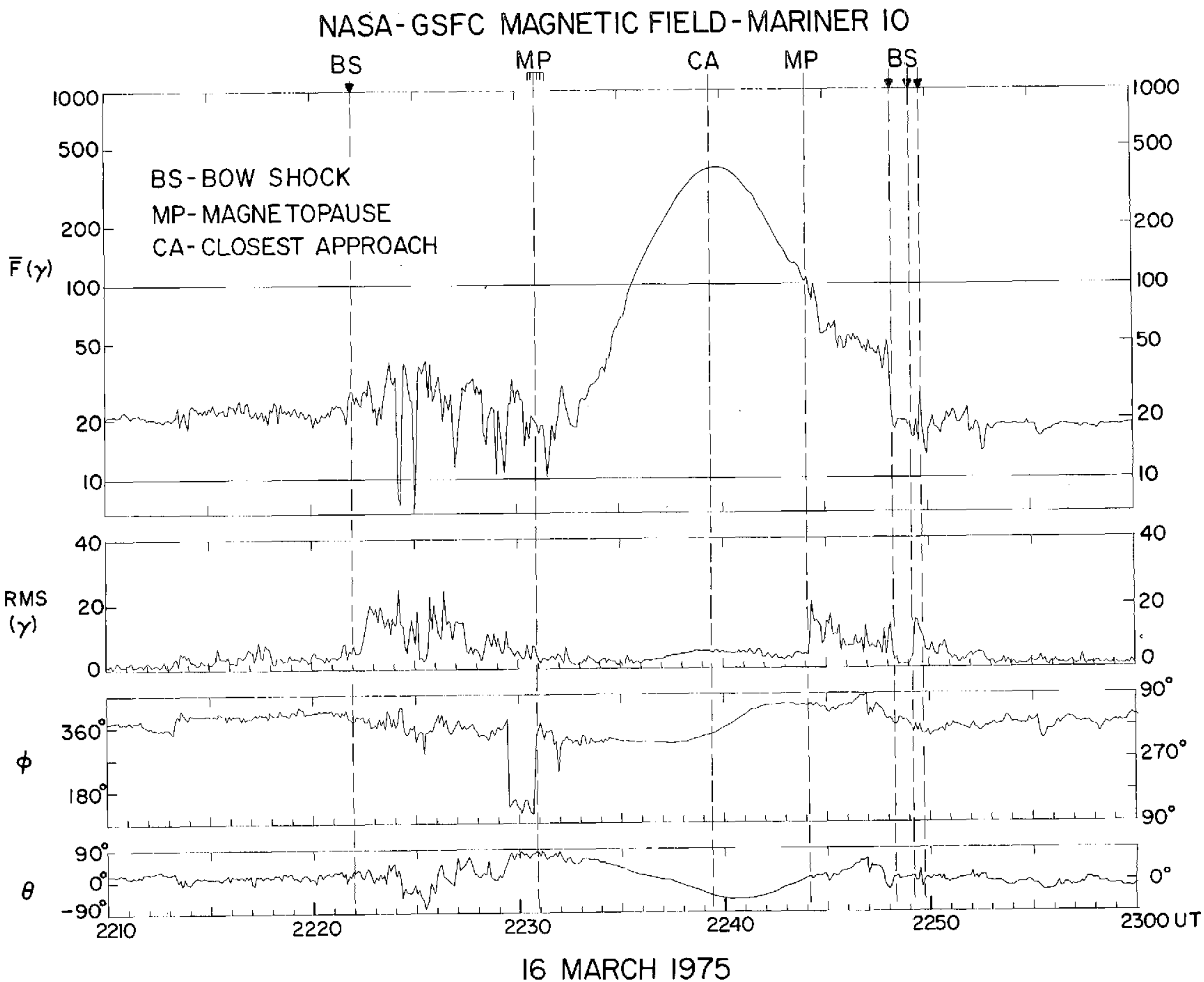

MARINER 10
MERCURY ENCOUNTERS
I and III
ALIGNED FLOW
M ∞ = 10
M A∞ = 20
SCALED BOW SHOCK
SCALED MAGNETOPAUSE
SOLAR
WIND
X ME
Y ME
Z ME
MERCURY
S
MP
BOUNDARY CROSSINGS
SHOCK (S)
MAGNETOPAUSE (MP)
VIEW FROM SUN
III ------ 16 MARCH 1975
I ——— 29 MARCH 1974
10³ km
+12
+6
-6
-12
-14
4
-4
+6
+12

Figure 1



NASA-GSFC MAGNETIC FIELD-MARINER 10
BS
MP
CA
MP
BS
BS-BOW SHOCK
MP-MAGNETOPAUSE
CA-CLOSEST APPROACH
F̄ (γ)
1000
500
200
100
50
20
10
RMS (γ)
40
20
0
φ
360°
180°
90°
270°
90°
θ
90°
0°
-90°
0°
2210
2220
2230
2240
2250
2300 UT
16 MARCH 1975

Figure 2