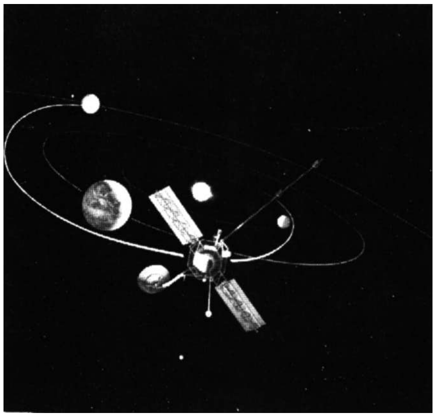

MARINER VENUS / MERCURY 1973

STATUS BULLETIN

Third Mercury Encounter Operations and Preliminary Science Results

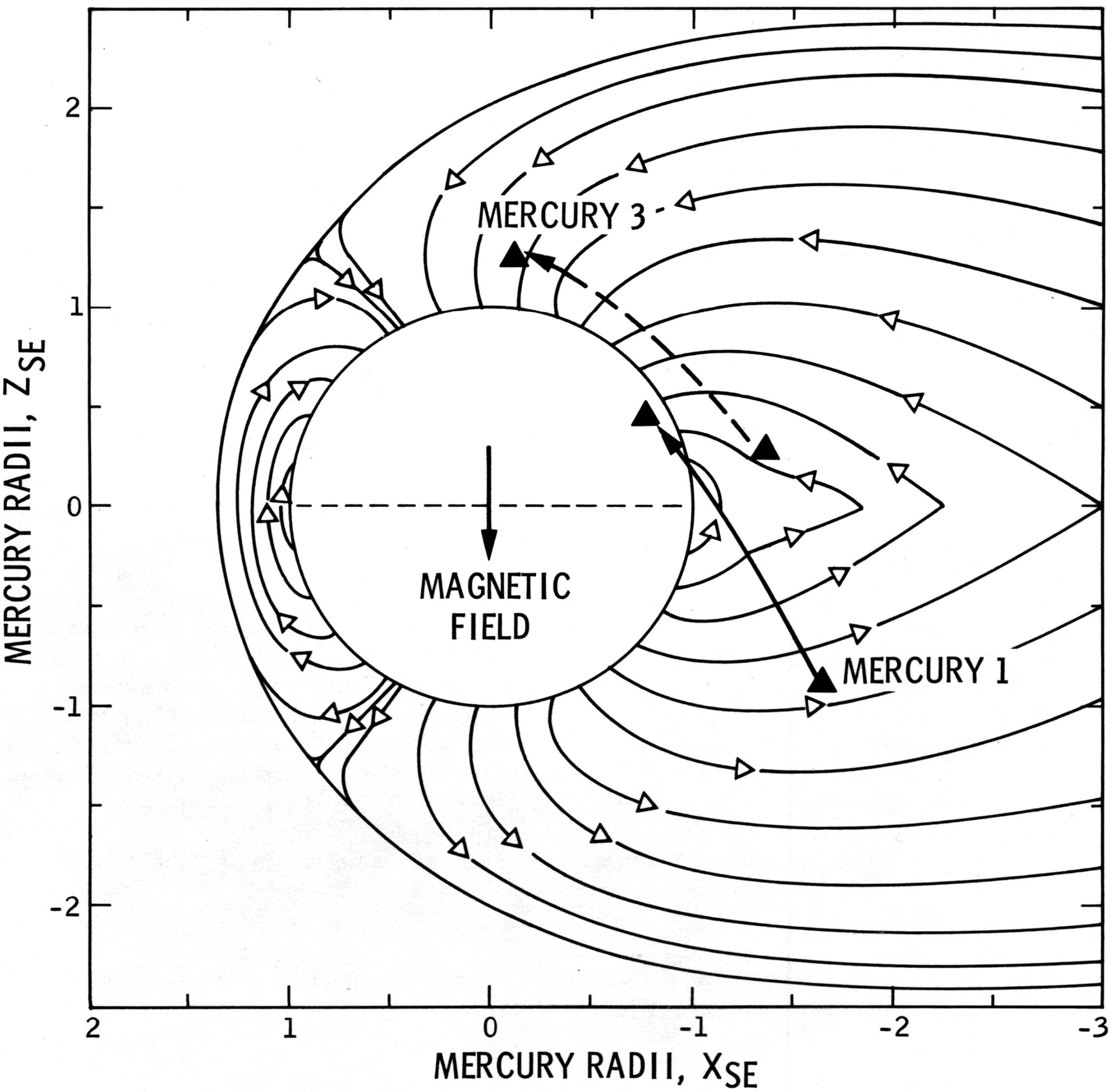

Fig. 1. Equatorial plane view of Mercury's magnetic field lines, showing portions of Mariner 10's path during first and third encounters within the planet's magnetosphere.

MARINER VENUS/MERCURY 1973 PROJECT OFFICE
Jet Propulsion Labratory California Institute of Technology
National Areonautics and Space Administration
Pasadena, California

3 April 1975

BULLETIN No. 38

MARINER 10 OPERATIONS DURING MERCURY ENCOUNTER

Mariner 10 exhausted its attitude control gas supply at approximately 11:25 GMT on 24 March 1975, and the spacecraft transmitter was turned off for the last time. (See Table 1.) The historic flight of Mariner 10 was over, 506 days and nearly 1.6 billion kilometers, (1 billion miles) of travel from liftoff on 3 November 1973.

Mariner's third encounter was the closest yet, both in distance from the planet (327 km) and in margin of success. Acquisition of its celestial roll reference, the star Canopus, had been accomplished a scant 36 hours before closest approach, after more than 72 hours of tense and often frustrating attempts to determine the spacecraft's roll position, rate, and, at times, even direction. An account of this final acquisition phase, essential to the accomplishment of a scientifically meaningful encounter (a roll reference was required to point the high-gain antenna to the Earth and the scientific instruments at Mercury) is given here in the words of William L. Purdy, Spacecraft Team Chief:

"The normal roll-search method of Canopus acquisition was ruled out since there was a possibility of exciting a roll-axis structural oscillation interaction with the long appendages which could result in a gas-usage rate of 15 millipounds per minute, dooming the spacecraft. Such an event had been experienced on 6 October 1974, just 2 weeks after the second Mercury encounter, when 200 millipounds of gas had been lost in space, and only 0.6 lb remained which had to last through 5.5 months of cruise, 3 trajectory correction maneuvers, and the third encounter. It was then that solar sailing* was initiated. The desired "zero-gas" Canopus reacquisition involved sending a command sequence that would enable the roll axis attitude control when Canopus entered the field-of-view of the star tracker. If the spacecraft (S/C) roll rate was slow enough, Canopus would still be acquired in the 18-minute round trip light time, and the acquisition would be accomplished without risking the possibility of the roll-axis oscillation being induced by a roll search. The spacecraft would then be placed in the roll-axis inertial control mode to preclude the possibility of a bright-particle incident causing loss of roll reference prior to or during encounter. The first good chance at acquisition, predicted by observing low-gain antenna (LGA) patterns during the DSN Station 63 (DSS 63) passes on 10, 11 and 12 March was estimated to be during a 3-hour tracking gap between DSS 63 and DSS 43 on 12 March. An attempt was made to slow the S/C roll rate in order to delay the Canopus crossing to the DSS 43 track, but was unsuccessful. It was at this point that the 64-m antenna passes assigned to the Helios Project were requested from Goldstone and Canberra on an emergency basis. The next acquisition attempt, on 13 March, resulted in stopping about 7 degrees beyond Canopus because the S/C roll rate was too high. The S/C was backed up and rolled to Canopus, but acquisition did not occur, since the S/C apparently was not backed up far enough. The S/C direction of roll was reversed, the S/C backed up approximately 140 degrees, stopped, and the high-gain antenna (HGA) pointed at Earth to get a good calibration on the roll position. Then, using the HGA pattern to confirm roll position, the S/C was allowed to roll drift to Canopus.

"The S/C was stopped 40 degrees short of Canopus to confirm the roll position, and again at 7 degrees short of Canopus. Tracking the HGA pattern in as the S/C rolled the last 7 degrees allowed the roll drift stop commands to be effective at the S/C while Canopus was still acquired, with the S/C in the all-axis inertial mode. The inertial reference in roll was updated to the celestial reference, the pitch and yaw axes to celestial reference, and the encounter sequence was started by turning on the TV camera beams and light flooding at 03:08 PDT (10:08 GMT) on Saturday, March 15."

Following Canopus acquisition, the encounter sequences were executed smoothly and as planned. The final log of Mariner 10 is given in Table 1.

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*A technique for roll axis control developed in flight by Jerry Hardman of the Boeing Ca. and Larry Schumacher of JPL under the supervision of William L. Purdy.

TABLE 1. FINAL LOG OF MARINER 10; 16—24 March 1975

Day	Date	PDT	Operation
Sun	16 Mar	15:40	Closest approach to Mercury; remained in gyro inertial control mode remainder of Mission except for center-of-pressure tests.
Mon	17 Mar	03:00	Last TV pictures taken; begin far-ultraviolet (UVS) scans of selected stars and nebulas.
Tue	18 Mar	all day	Magnetometer calibrations and UVS scans.
Wed	19 Mar	all day	Continue ultraviolet scans of regions in space.
Thu	20 Mar	19:00	Last of UVS Scan sequences; engineering tests.
Fri	21 Mar	09:30	Attempt to open Plasma Science Experiment's SEA door, which had not opened during entire mission, but without result.
		10:00	Turn Solar Panels to their limits to note effect; also slew Scan Platform to 180 deg limit.
		15:00	Test Data Storage Subsystem and Flight Data Subsystem to attempt to activate tape recorder.
		19:45	Initiate Radio Transmitter shutdown sequence.
		20:45	Send Direct Command 55 to turn off TWT (DC 55).
Sat	22 Mar	10:45	Send DC 54 to turn on the Radio TWT.
		20:00	Reload the Central Computer and Sequencer.
Sun	23 Mar	00:30	Begin all-axis drift mode to determine spacecraft center of pressure by solar-wind interaction.
		02:50	Send DC 55 to turn off Radio TWT.
		23:55	Send DC 54 to turn Radio back on (20 min round trip).
Mon	24 Mar	00:19	DSN Station 63 promptly acquires signal, in lock.
		03:50	Set spacecraft in all-axis drift mode to see if solar sailing might be possible.
		04:16	Turn on gyros to attempt to reacquire Canopus, attempt fails when attitude control gas is exhausted.
		04:54	Spacecraft loses both Sun and Canopus references.
		05:00	Sent DC 55 to turn off Radio TWT (for last time).
		05:21	DSN Station 63 receiver loses signal lock, indicating that the Radio was indeed turned off. The last signal received indicated that the spacecraft had pitched 21 deg from the Sun, and the temperature was rising because the sunshade no longer shaded the electronics.

PRELIMINARY THIRD ENCOUNTER SCIENCE RESULTS

A press conference was held at 1:30 pm PDT on Monday, 17 March 1975. A summary of the statements made by science investigators at that time follows:

DR. JAMES A. DUNNE, PROJECT SCIENTIST, JPL

As the Mariner operations team struggled with the problem of Canopus reacquisition, the Pioneer (10 and 11) and Helios flights continued collecting important scientific data in previously unexplored regions of the solar system. Helios was in the critical phase near perihelion, some 28 million kilometers from the Sun. Knowing this full well, I was nevertheless compelled to ask for two station passes (Goldstone and Canberra) scheduled for Helios following the loss of the Canopus crossing due to a tracking gap on 12 March. The cooperation of the Deep Space Network and the Helios and Pioneer projects personnel in yielding their scheduled tracking time during this and other critical periods is gratefully acknowledged. On Friday, 14 March, I called Mr. Panitz, the Helios Mission Manager, at his home in Germany to explain why we had preempted his spacecraft tracking period at DSS 43 in Canberra the previous day, and he had the good grace to wish Mariner 10 a successful third encounter.

Boeing design engineers are to be commended for incorporating the flexibility into the spacecraft without which Mariner 10 could not have survived for a third encounter. The solar sailing procedure had not been anticipated before launch. The necessary calibration data relative to spacecraft orientation toward the Sun line and the resultant torques exerted by solar radiation on various appendages as a function of their attitude in space had not been obtained. All experimenting had to be done with a half-dead spacecraft in flight. The development of a workable solar sailing control technique is therefore a major accomplishment in space flight technology.

For this and other reasons, I want to acknowledge the extreme efforts and inventiveness of our Spacecraft Team, composed of both Boeing and JPL people, as well as our Sequence Generation and Navigation Teams, who responded to the spacecraft anomalies and emergencies in a truly professional, capable and outstandingly innovative manner. All Science Team members extend their grateful appreciation to the Mariner Mission Operations Team under the direction of Dallas F. Beauchamp, Chief of Mission Operations, and everyone involved in this outstanding accomplishment. In the past few days, many worked around the clock for almost 48 hours, making the successful third encounter with Mercury possible.

The objective for the third encounter was to obtain the best possible data on Mercury's magnetic field. Mariner 10 had been targeted for a closest approach altitude of 200 km above the planet's surface. There was an orbit determination uncertainty which corresponded to a 100 km one-sigma variation in range, giving a 2% probability of impact, which we accepted in the interest of obtaining a close flyby. Fortunately, the gods of chance did not come to collect their 2%. Our confidence on this point was shaken somewhat around noon on encounter day when Dr. Jeremy B. Jones, Navigation Team Chief, reported that the latest orbit determination solutions were indicating an impact. Worse yet, the pseudo-residuals started climbing rapidly about an hour before periapsis, indicating that the flyby point was going to be closer than anticipated. As it turned out, we flew by Mercury at about a 327 km altitude. Encounter time was 15:39:24 PDT (22:39:24 GMT), and the sub-spacecraft latitude at periapsis was about 70°N. About 300 quarter-frame TV pictures were taken, four of which are shown at the end of this Bulletin. No infrared data were obtained because the IR instrument is body-fixed to point in a direction near the spacecraft orbit plane, and it did not see the planet during the polar region passage. Excellent ultraviolet spectrometry data were obtained, and it is expected upon further analysis that the UV experimenters will be able to accurately define the spatial distribution of helium around Mercury.

The third encounter yielded the best celestial mechanics data of the Mission because of the close passage and the absence of an Earth occultation. Good range points were measured on both sides of the periapsis, along with uninterrupted doppler data which should provide additional information relative to Mercury's internal structure. Geological mapping of the hemisphere covered by TV during the first two encounters is now in progress, and third encounter data will be of benefit to this task. The highest resolution obtained during the third encounter is probably about 100 meters, rather than the expected 50 meters, because of a combination of the low exposure settings selected to avoid image smear and the reduced data rate (6 bit pixels rather than 8). The 50-m pictures are therefore very dark, and exhaustive computer processing will be required to determine if any scene detail can be pulled out.

DR. NORMAN F. NESS, MAGNETOMETER EXPERIMENT, GODDARD SPACE FLIGHT CENTER

The magnetic field experiment on Mariner 10 during the third encounter dramatically confirmed and extended the results obtained a year earlier at the Mercury 1 encounter. The magnetic field which is responsible for deflecting the flow of solar wind is unquestionably intrinsic to the planet and is not associated with any complex or exotic induction process associated with the solar wind interaction with the planet.

Based upon the Mercury 1 encounter results and a mathematical analysis, a modest planetary magnetic field with a strength of 350 gamma at the equator and 700 gamma in the polar region was identified (F ig. 1). The magnetic dipole axis was tilted 7 degrees from the axis of rotation of the planet. The Mercury 3 encounter trajectory (Fig. 2) was very carefully selected to enhance the ability of the data to illuminate more fully the characteristics of the planetary magnetic field and its deformation by the solar wind. A model magnetosphere was constructed which permitted predictions of the expected bow shock and magnetopause crossings as well as the maximum magnetic field to be measured.

The actual observations of the characteristic bow shock and magnetopause show a perfect correspondence with predictions (Fig. 3). The maximum field measured was 400 gamma, only slightly less than the 500 gamma value predicted pre-encounter. The difference is understood since the actual flyby occurred at an altitude approximately 127 kilometers higher than predicted pre-encounter and used in the model.

The composite results of the magnetic field measurements establish unequivocally that the planet Mercury is one of the few magnetized terrestrial planets in our solar system. Neither Venus nor the moon has even a modest magnetic field. The results on Mars, due to investigations by the USSR, are somewhat equivocal, partially associated with the less than ideal trajectory of the spacecraft Mars II, III and V.

The origin of the magnetic field is definitely associated with the planetary interior. Whether it is due to permanently magnetized rocks or an active dynamo mechanism in a fluid core is at present unclear. However, the permanent magnetization theory requires a very special sequence of events occurring during the formation and evolution of the planet. The active dynamo mechanism faces some difficulties because we are uncertain about the exact structure of the planetary interior. Indeed, it is expected that careful analyses of the magnetic field measurements at Mercury 3 and comparison with those of Mercury 1 shall contribute to a resolution of this issue. The existence of the planetary magnetic field places specific constraints on the planetary interior in either model, which can be tested with other complementary data including other measurements by Mariner 10. For example, the distribution of mass within the interior may be estimated by a careful analysis of the tracking data following the deflection of the spacecraft's trajectory by Mercury.

The magnetic field experiment was conducted by a team of investigators from the Goddard Space Flight Center in Greenbelt, Maryland. Dr. Norman F. Ness is the principal investigator, and co-investigators are Mr. K. W. Behannon and Dr. R. P. Lepping of GSFC and Prof. Y. C. Whang of the Catholic University in Washington, D.C.

DR. CLAYNE M. YEATES, PLASMASCIENCE EXPERIMENT, JPL

Data obtained with the plasma science instruments on Mariner 10 provided definite indications that the interaction between the solar wind and Mercury's magnetic field appears, to a remarkable degree of detail, to be a scaled-down version of the interaction of the solar wind and Earth's magnetic field. Magnetosphere boundary locations and the bow shock (Fig. 2) observed during Mercury 3 are consistent with the locations that were previously scaled from Earth's magnetosphere on the basis of the Mercury 1 field and particle observations (Ogilvie et al., 1974; Ness et al., 1974). In addition, the cool and hot regions of the plasma sheet and also a polar low-flux region (similar to that at Earth's polar cap or the high-latitude magnetotail) are all consistent with a similar scaling on the basis of the magnetic field model deduced from Mercury 1 data (Ness et al., "The Magnetic Field of Mercury: Part I," J. Geophys. Res., in press). This new evidence strongly supports the idea that Mercury's magnetic field is largely of intrinsic planetary origin. The polar low-flux region was observed for the first time during Mercury 3. Distinctions between the cool and hot plasma sheets became apparent from a comparison of the Mercury 1 and 3 data.

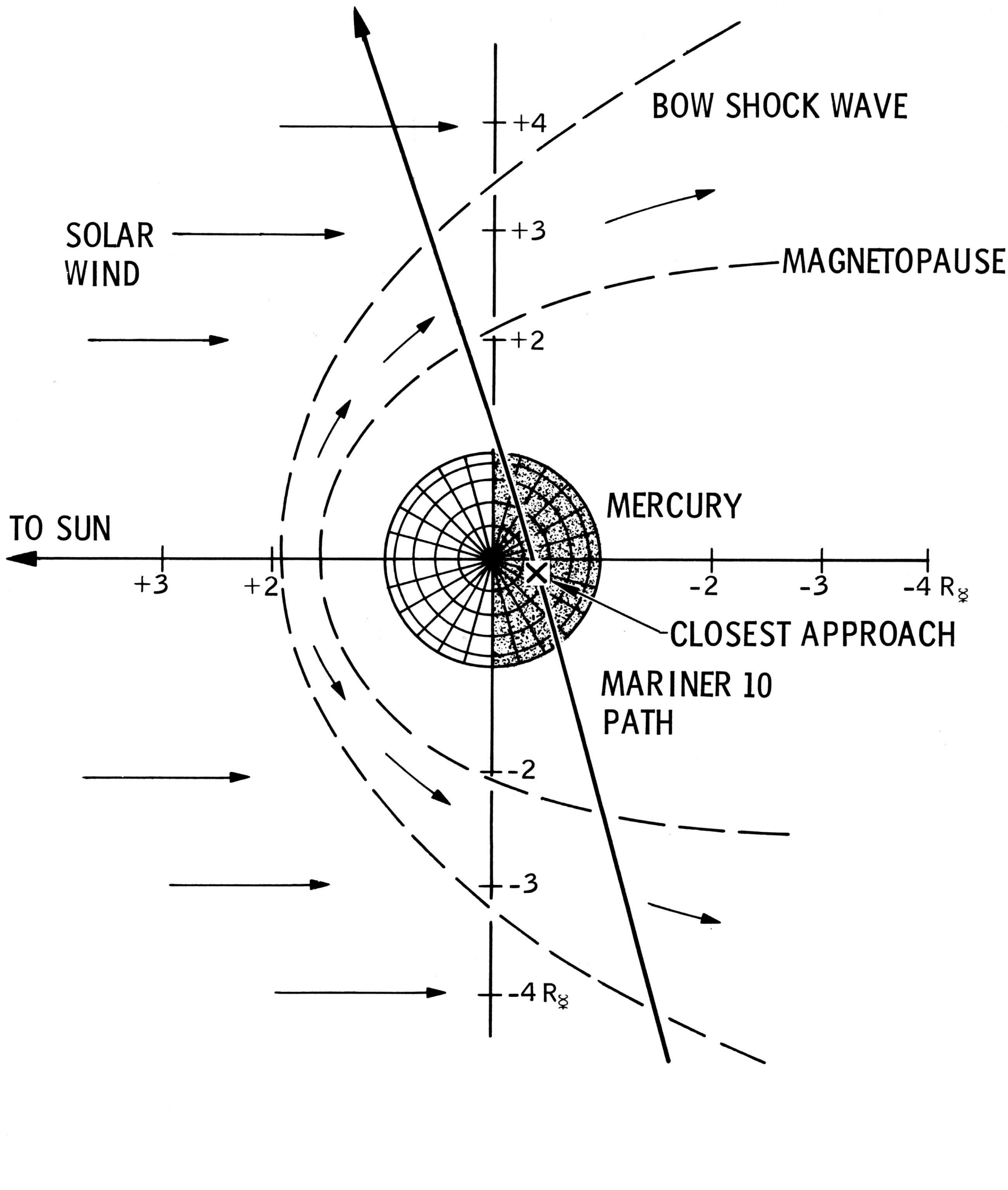

Fig. 2. Mariner 10's path during third Mercury encounter, looking down on north polar region and showing solar wind interactions with planet's magnetic field.

Figure 4 shows the trajectories of both the Mercury 1 and 3 encounters by Mariner 10 together with the orientation of Mercury's magnetospheric equator, given by the model of Ness et al. Predicted locations of the magnetopause and of the bow shock are shown for Mercury 3 as well as the observed boundaries and plasma regions on both encounters. The inbound crossings of the magnetopause and the bow shock occur at almost precisely the predicted locations; the outboard crossings were only slightly farther out than predicted. After crossing the inbound magnetopause, Mercury 3 encountered a region of fairly intense but relatively low energy electron population (spectral peak at ~ 150 eV, e-folding energy ~ 50 eV), very similar to the cool plasma sheet seen in Earth's magnetic tail at appreciable distances from the magnetospheric equator. A similar region was seen on the inbound pass of Mercury 1. In Fig. 4, it should be noted that Mercury 1 is well below the magnetospheric equator, and Mercury 3 is well above. The intensities and energy spectra seen in Mercury 1 and 3 are similar when allowances are made for the fact that during Mercury 3 the instrument (or spacecraft) appears to be at a positive potential of about 40 volts relative to the plasma; this difference is tentatively attributed to aging effects.

Near the center of the Mercury 3 encounter trajectory, where the projection of the spacecraft on the magnetosphericequator is behind (or within) the planet (see Fig. 5), a region of very low electron flux was observed, having a very soft energy spectrum (e-folding energy < 10 volts). This region was not encountered, however, during Mercury 1 because at this point the spacecraft was close to the magnetospheric equator; whereas in Mercury 3, it was nearly at its maximum height of about 1 planetary radius above the magnetospheric equator. If the magnetosphere is scaled relative to Earth, this region corresponds to about 7 Earth radii. At such a location in Earth's magnetosphere, very low particle intensities are also observed this region corresponding to magnetic field lines that emanate from Earth's polar cap. The origin of these few observed low-energy particles is still an unsettled and controversial question in the case of Earth and is equally uncertain for Mercury; they could originate from Mercury's magnetosheath or from its tenuous atmosphere. Further study of the observed spectra should help clarify this question. During Mercury 3, significant time variations are seen in this low-intensity population.

The outbound traversal of the magnetosphere on Mercury 3 is similar to the inbound, as expected because the spacecraft is at nearly the same height above the magnetospheric equator. By contrast, on Mercury 1 the electron population seen on the outbound traversal was quite hot (spectral peak above the instrument range, e-folding energy at hundreds of eV), much hotter than the corresponding portion of the inbound traversal. As can be seen from Fig. 4, the spacecraft while outbound was nearly at the magnetospheric equatorial plane, indicating that the plasma behavior is the same as in the case of Earth, where the plasma near the equator is hotter than at the outer regions of the plasma sheet in the magnetotail.

The plasma science experiment was conducted by a team of nine investigators from five organizations under the leadership of Dr. H. S. Bridge, MIT Center for Space Research, Principal Investigator. Co-investigators included Dr. C. M. Yeates of JPL, Dr. H. A. Lazarus of MIT, Dr. K. W. Ogilvie of GSFC, Dr. J. D. Scudder of GSFC, Dr. R. E. Hartle of GSFC, Dr. G. L. Siscoe of UCLA, Dr. J. R. Asbridge of Los Alamos, and Dr. S. J. Barne of Los Alamos.

DR. JOHN A. SIMPSON, CHARGED PARTICLE EXPERIMENT, UNIVERSITYOF CHICAGO

In the presentations of Dr. Ness and Dr. Yeates, the discussion concerned the major magnetic field that exists around the planet Mercury and the interaction of that field with the solar wind plasma (Fig. 5) which has relatively low energy; i.e., 10 to 150 eV. The charged particle experiment measures the intensities of protons and electrons that range from a few percent to very close to the velocity of light; i.e., 0.5 to 2 MeV. Although these high-energy particles do not carry enough energy to distort a planet's magnetic field, they are at the core of energy conversion from magnetic fields into high-energy particles by an acceleration process.

The high-energy particles come from distant reaches of a planet's magnetic field which cannot be reached by the spacecraft itself. Therefore these particles can be used as probes of a much larger region of a planet's environment than by the actual probing of a magnetometer. Interesting features about the scale properties of a magnetic field can be deduced.

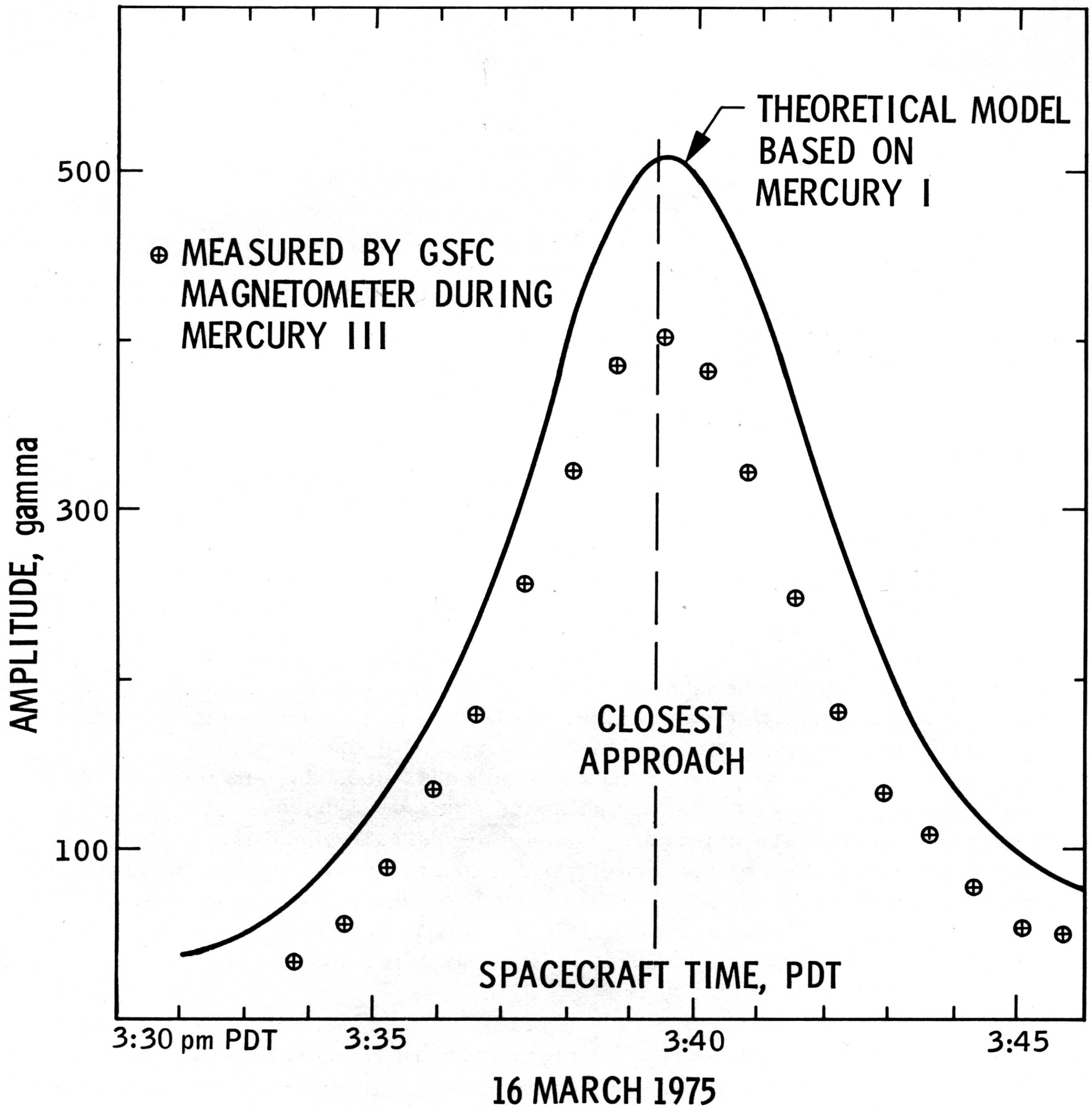

Fig. 3. Magnitude of magnetic field observed during third Mercury encounter.

A preliminary examination of the charged particle data revealed two interesting phenomena. The first was that intense bursts of radiation were observed by the Charged Particle Experiment as Mariner 10 approached and passed by Mercury during the first encounter. The magnitude or intensity of this event was very great, and the duration very brief. Such events are apparently related to solar electromagnetic storms that have been observed on Earth. The second phenomenon was a fortuitous first actual test of the idea that the Sun is emitting a steady stream of nuclear particles along its magnetic field lines that extend outward from the Sun and are in corotation with it.

During the first Mercury Encounter bursts of high-energy radiation were observed that extended several orders of magnitude in intensity, dying away very rapidly as the spacecraft passed into the occultation region. As the particle intensities died down, they appeared to ring or oscillate at 6-sec intervals. This phenomenon may be due to a resonant flapping of the magnetic tail like a flag waving in a breeze. Both low-energy protons and electrons appear to be accelerated and taking part in this mechanism. This phenomenon occurs so rapidly that there is not enough time to accelerate them by a process as in a bevatron or cyclotron. There is hardly enough time to execute even one gyro radius in a typical magnetic field. It must be an unstable and explosive event that promptly dies away. It is related to the generation of a momentary strong electric field. During Mercury 1, the pass was on the dark side, close to the planet's magnetic equator, which is a relatively weak region near the neutral sheet or the merging region for the magnetic field. This merging can be considered as an energy source for particle acceleration.

In Fig. 6, the results of the charged particle experiments during Mercury 1 are compared with those of Mercury 3. During the cross-polar flight of Mercury 3, no unusual data were expected. The particles would have to fan out and reach the higher latitudes where the field was expected to be stronger. A giant burst of 300 keV electron radiation was, however, experienced. The Mercury 3 data are shown in Fig. 7.

About 2 days before Mariner 10 encountered Mercury, the interplanetary radiation of protons was observed to be rising gradually to a factor of 10 above the normal background level in interplanetary space. Then, as Mariner 10 passed behind Mercury, the particle energy level dropped to the quiet level. In Fig. 8, we are looking down on the Sun, and the magnetic field lines are seen to spiral outward, where they are frozen into the plasma. One curved line passes Earth where it is being observed by the IMP-8 satellite orbiting around Earth. About 4 days later, a particle burst of the identical energy range was detected by the Charged Particle Experiment on board Mariner 10. The Sun's 13.3 deg/day rotation rate is seen to shift the plasma radiation line, which has a broad sector structure, about 55 deg in 4 days, and this same line then passes Mercury with protons having 10 times the normal background energy.

In addition to the Sun being a source of occasional impulsive events like solar flares, the Sun also has many active centers that emit an almost continuous particle population distribution. For almost 9 years, this problem has been studied at the University of Chicago at a distance of 1 AU from the Sun. Now, Mariner 10 has provided a test situation that demonstrated the dropout of the burst particles as the spacecraft passed behind Mercury. As the particles flow outward along the Sun's field lines, they spiral or loop around these frozen-in magnetic fields. The radius of this spiraling action does not appear to differ greatly from the radius of Mercury. Nature provided us with a giant shutter of the right size to give evidence of the continual emission of nuclear matter from the Sun. The energy spectrum of the helium component emitted appears to be 0.1 of the proton level and has the same spectral pattern. Figure 1 shows an equatorial plane view of the Mariner 10 flight path on which the field lines are shown along with the region in which the burst event occurred. The collapse of the magnetic fields occurred in about 100 sec. This collapse may serve as an energy conversion source to accelerate nuclear particles. This information may help increase our knowledge of the effects of magnetic storms on Earth.

The charged particle experiment was conducted by Dr. J. A. Simpson, principal investigator, and Mr. James E. Lamport, co-investigator, both of the Enrico Fermi Institute at the University of Chicago.

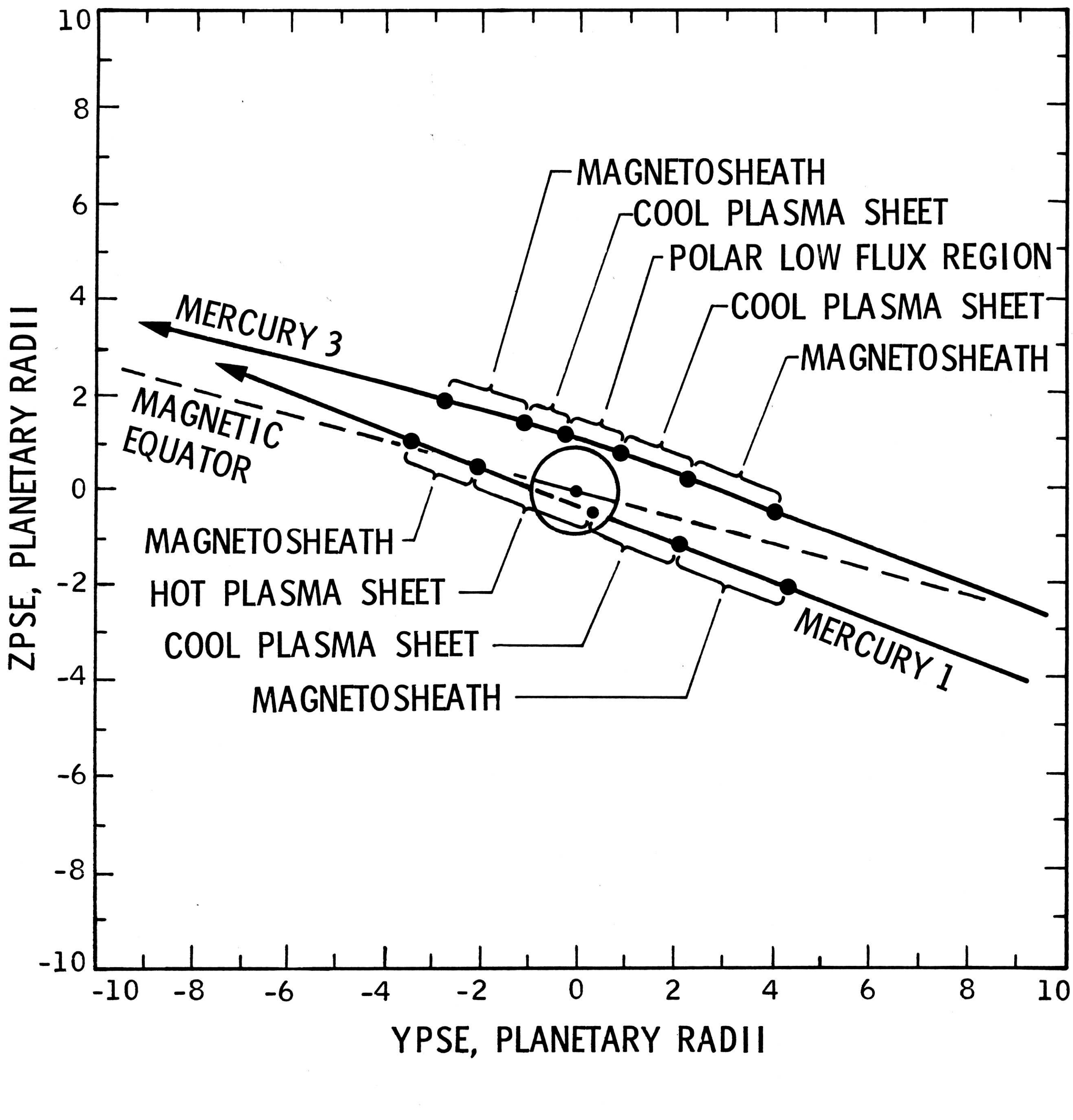

Fig. 4. Relative locations of Mercury's magnetosheath and its cool and hot plasma sheets observed during both encounters, viewed from Sun.

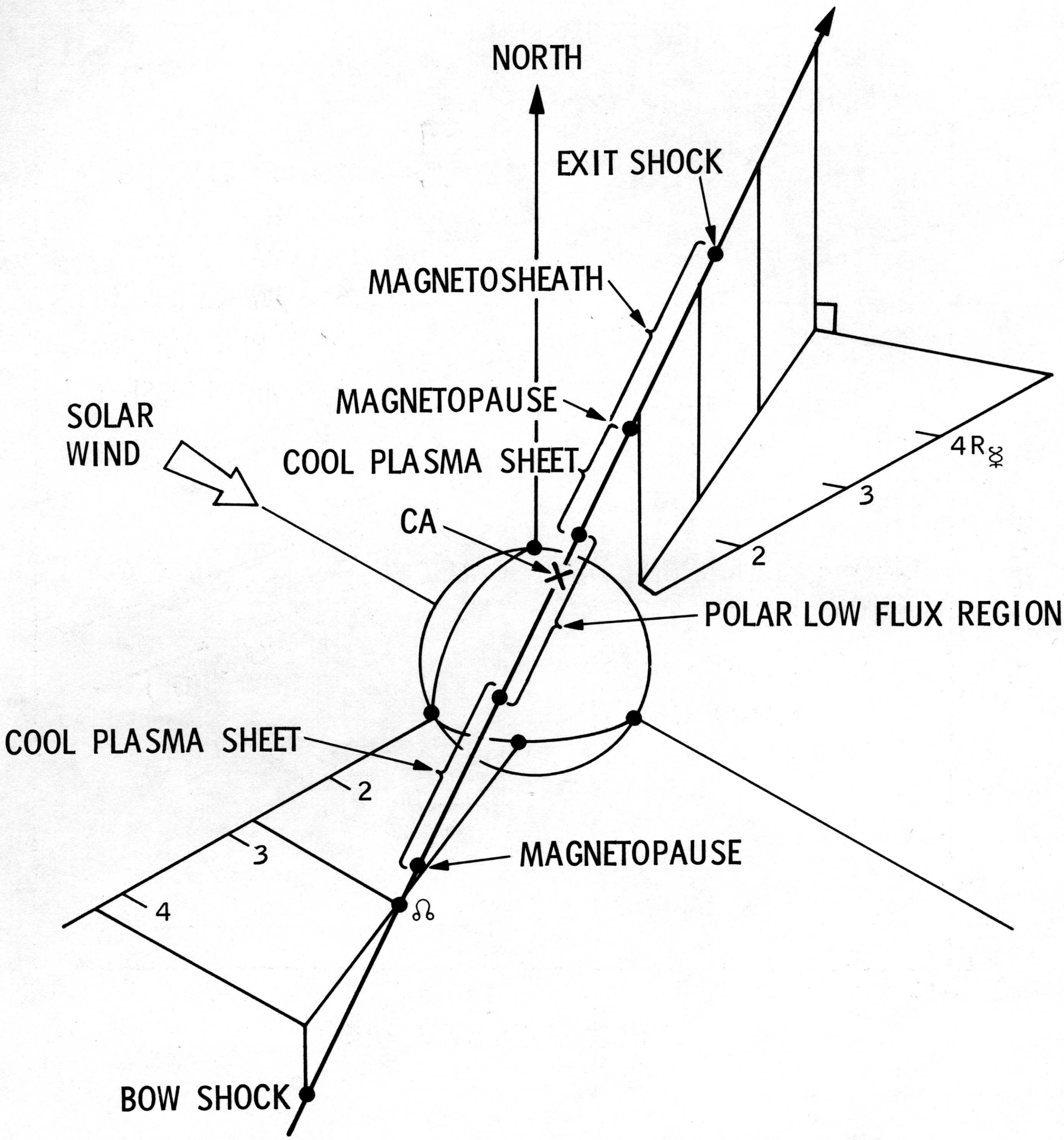

Fig. 5. Mercury 3 encounter-path plane view of magnetosheath and plasma sheet locations.

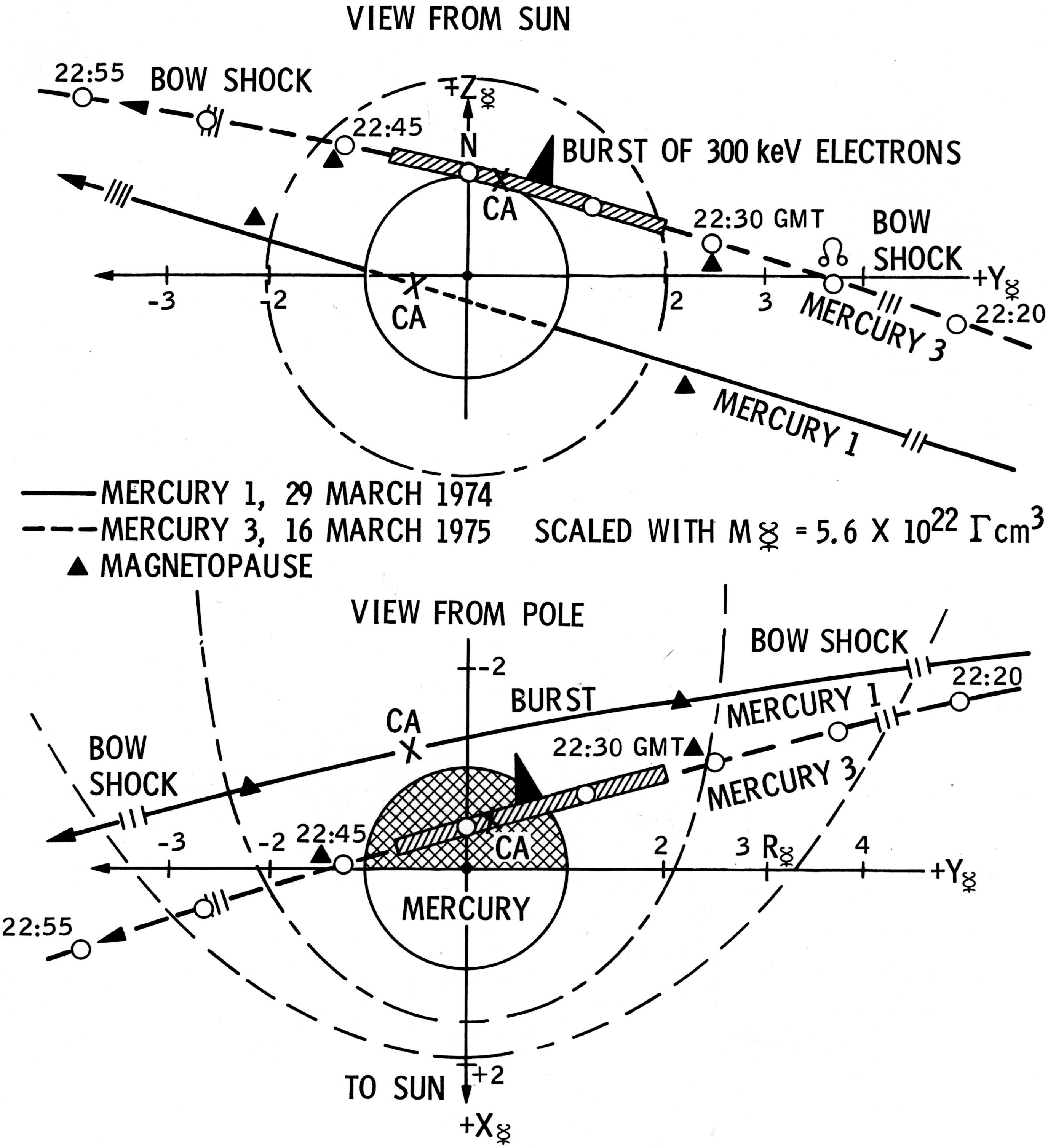

Fig. 6. Two views of Mercury 1 and 3 encounters showing locations of observed bow shock waves, magnetopause and high-energy particle burst event.

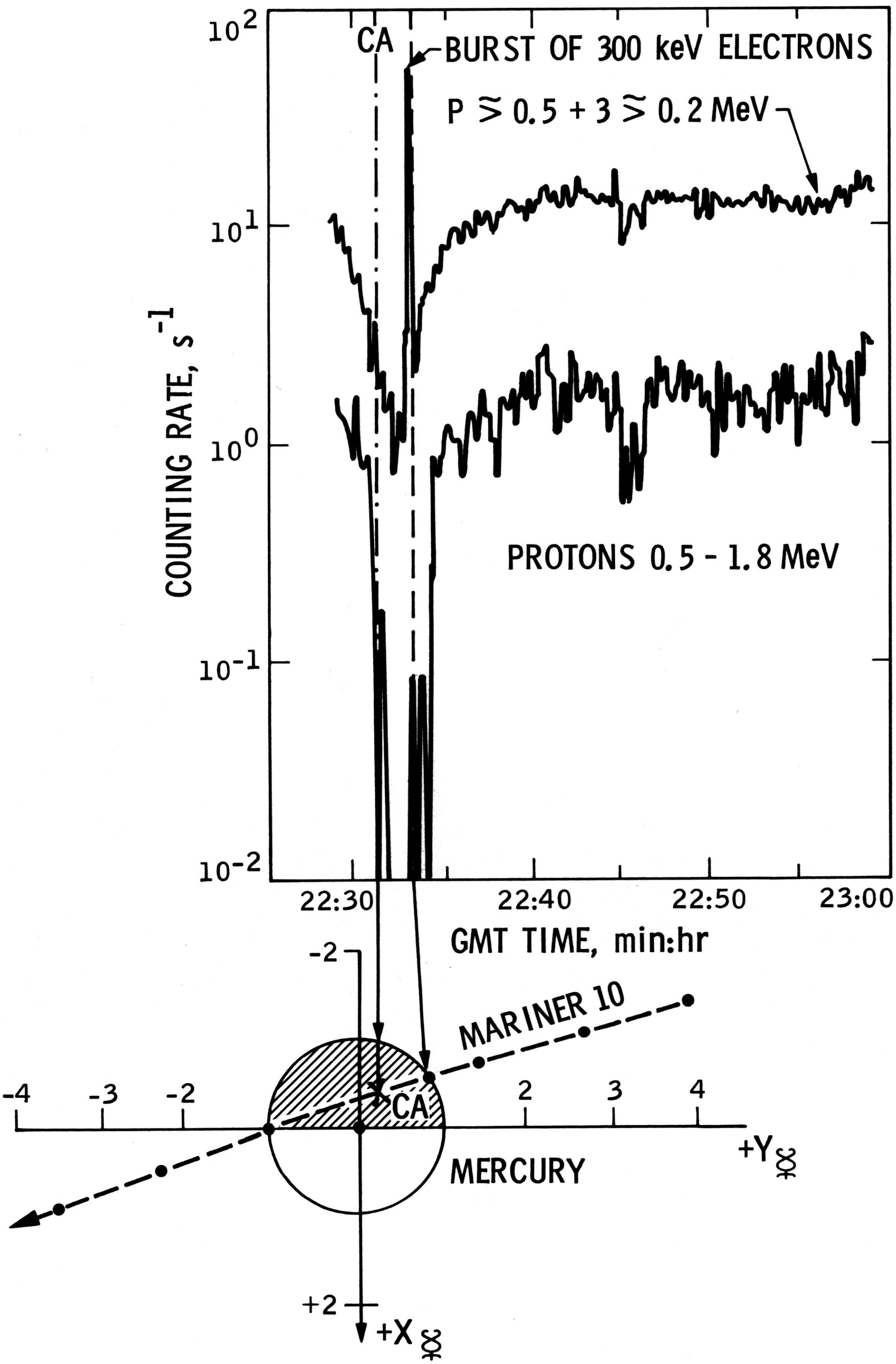

Fig. 7. Charged particle count profile, showing burst of 300 keV electrons observed during Mercury 3.

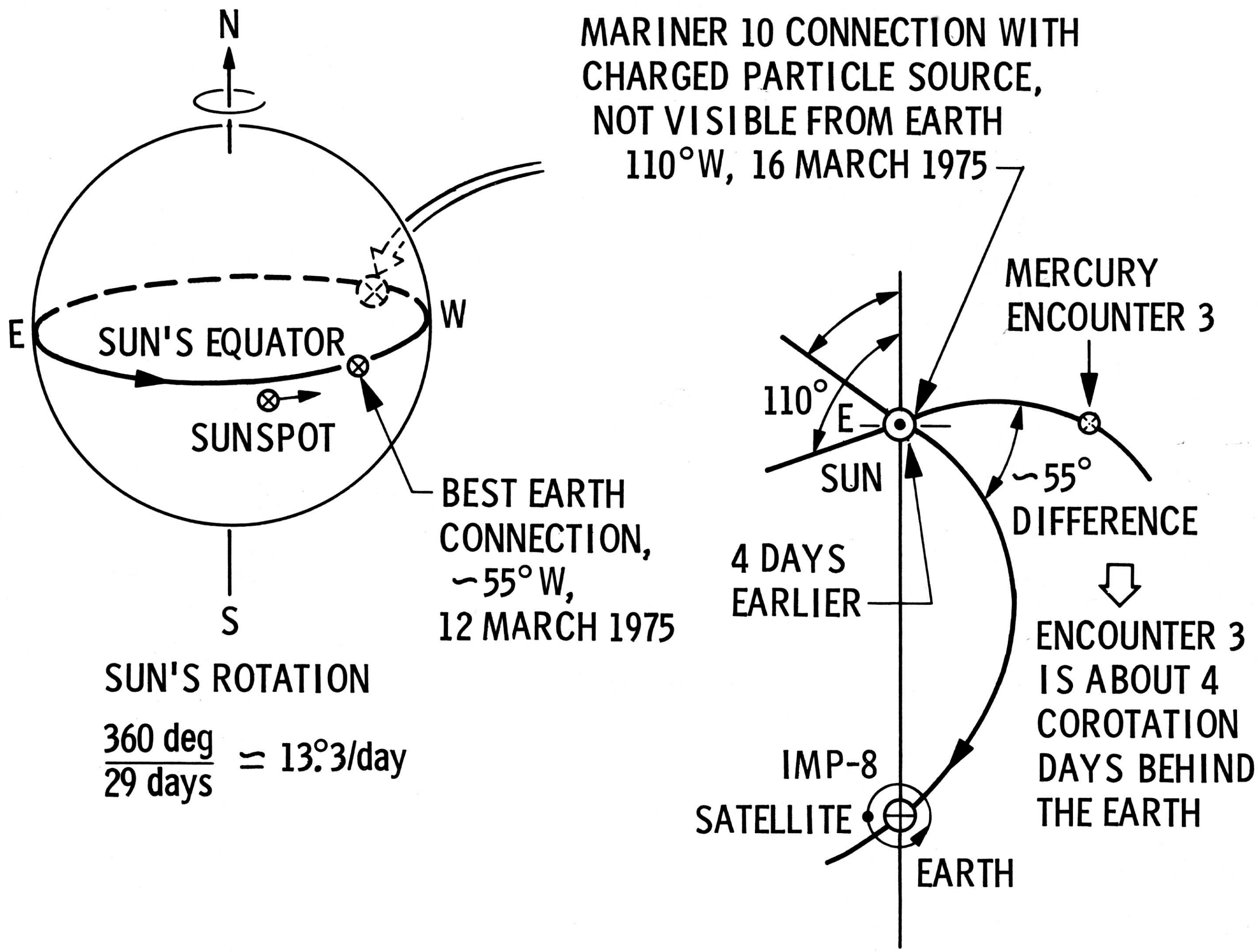

Fig. 8. Spiraling solar magnetic field line frozen into plasma stream, observed at Earth and also during Mercury 3 encounter about 4 days later.

FAREWELL TO MARINER 10

The flight of Mariner 10 is now history. Mr. Robert J. Parks, Assistant Laboratory Director for Flight Science and acting Mariner 10 Project Manager, reports that Dr. Fletcher, NASA Administrator, personally telephoned Dr. Pickering and W. Eugene Giberson, who directed the Mariner Venus-Mercury Project from inception to its second Mercury Encounter, to congratulate them on the performance of Mariner 10 during its extended mission, particularly the third Mercury encounter. In Mr. Parks' words: "This clearly indicates the high level of interest, appreciation and recognition that this mission has generated. This recognition is clearly deserved, and it is gratifying to see this specific demonstration that it is appreciated."

This last Mariner 10 status bulletin ends with the words of Dr. Ness, expressed in a telegram to Dr. Dunne:

"As the Mariner 10 extended mission draws to a close, those of us at the Goddard Space Flight Center associated with the magnetic field and plasma science experiments wish to take this opportunity to express our most sincere appreciation for the efforts expended by you and your staff to make this a scientifically rich and rewarding mission. In particular we feel that the hard work put into designing the Mercury III encounter science sequence paid off handsomely in providing results demonstrating that Mercury does possess an intrinsic magnetic field and a magnetosphere which is remarkably similar in structure to that of the Earth. These results should stimulate new theoretical work on planetary magnetism and also provide new insights into the physics of the interaction between the solar wind and magnetic barriers. To everyone else at JPL who has also helped to nurse the mission through to its brilliant conclusion, we offer our heartiest congratulations for a job well done and our thanks for helping us obtain these exciting and scientifically important measurements."

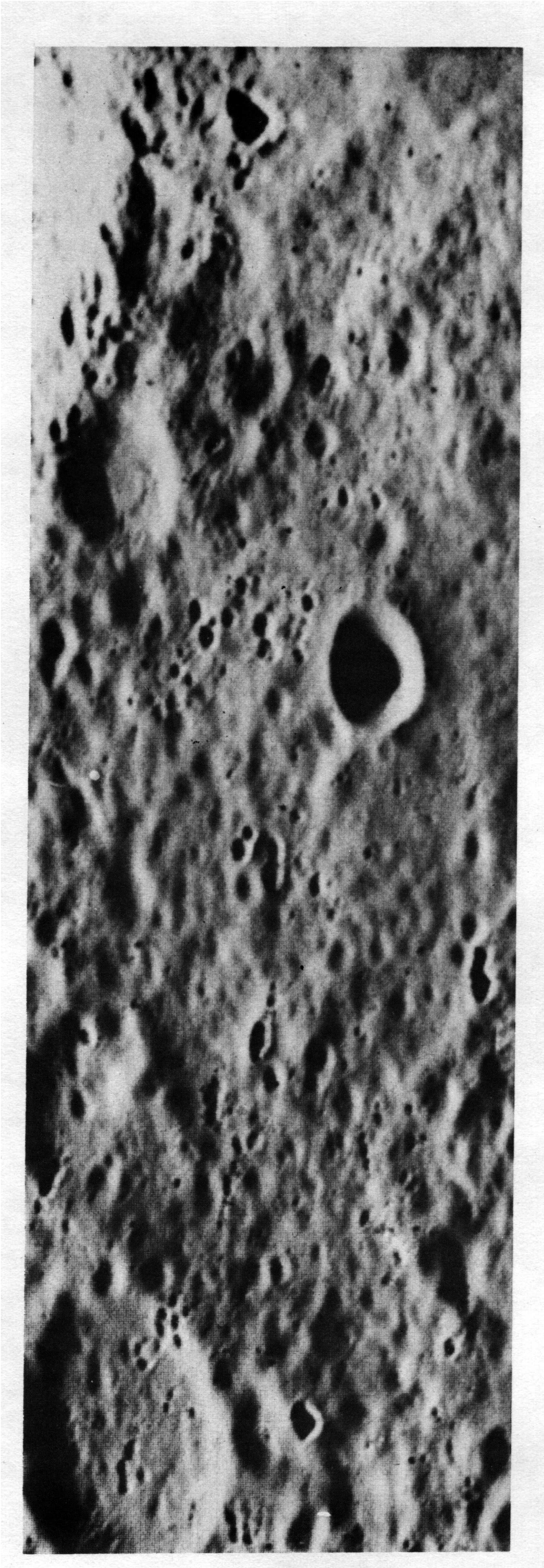

Fig. 9. About 18 minutes before Mariner 10's closest approach to Mercury on 16 March 1975, this crater-covered area was photographed. The TV picture is about 70 km (43 mi) long and was taken from a distance of 10,400 km (6500 mi). The crater Kuiper, one of the brightest craters on Mercury, is just off the picture to the lower left. A chain of secondary craters made by ejecta from Kuiper runs from the lower left corner toward the center. Objects as small as 200 meters (650 ft) can be observed.

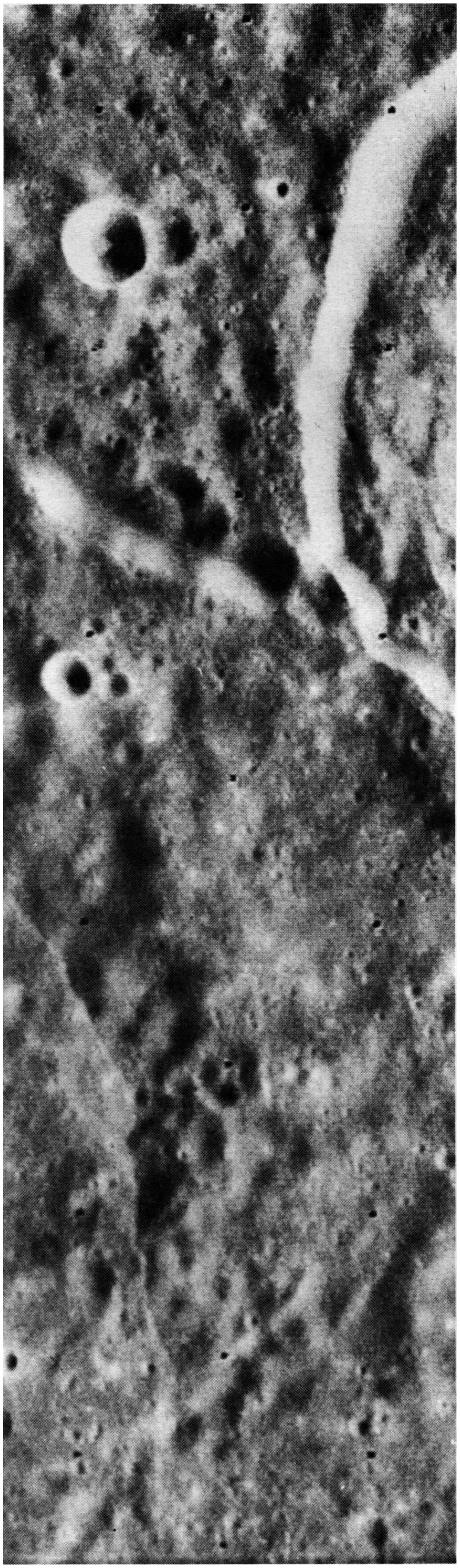

Fig. 10. Shortly after Mariner 10 grazed the edge of Mercury on 16 March 1975, the rim of a 50-km (30 mi) diameter crater was photographed. The picture is 120 km (75 mi) long and was taken from a distance of 17,000 km (10,500 mi). A small hill or valley about 400 meters (1300 ft) wide and 50 km (31 mi) long is visible as a thin bright streak in the lower left corner of the picture.

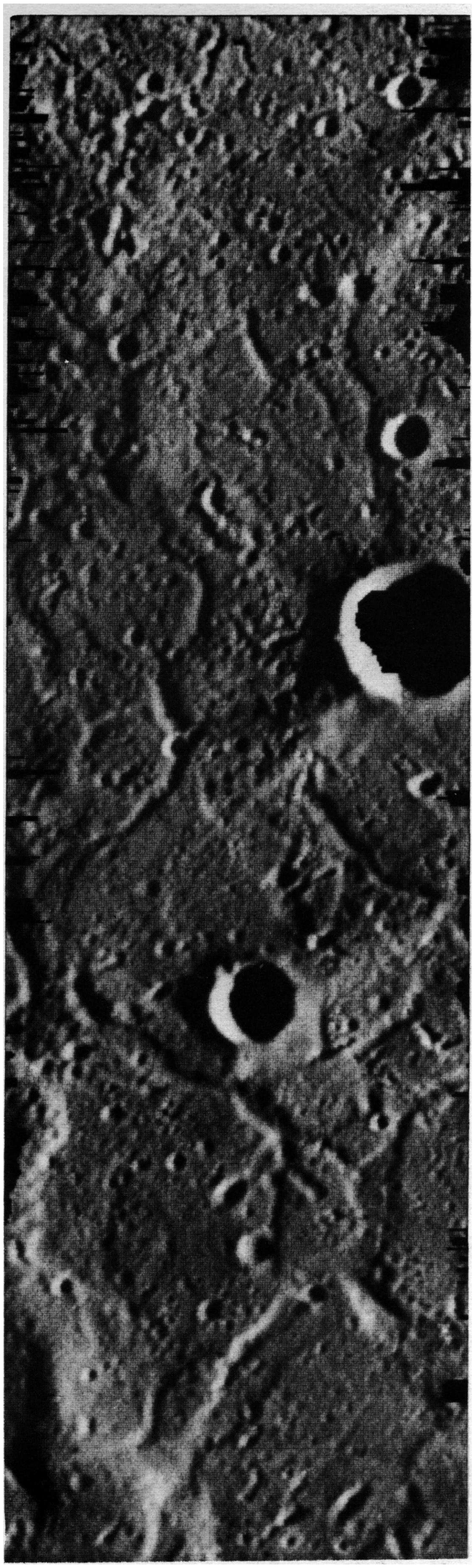

Fig. 11. About 34 minutes after Mariner 10 swept past Mercury, a high-resolution glimpse was obtained of the fractured and ridged plains of the Caloris Basin at a range of 19,000 km (11,800 mi). Almost all of Mercury's illuminated surface had been covered by Mariner 10's TV cameras at somewhat less resolution during the first two flybys, in March and September 1974. This picture shows an area located at 31°N Lat and 183°W Long.

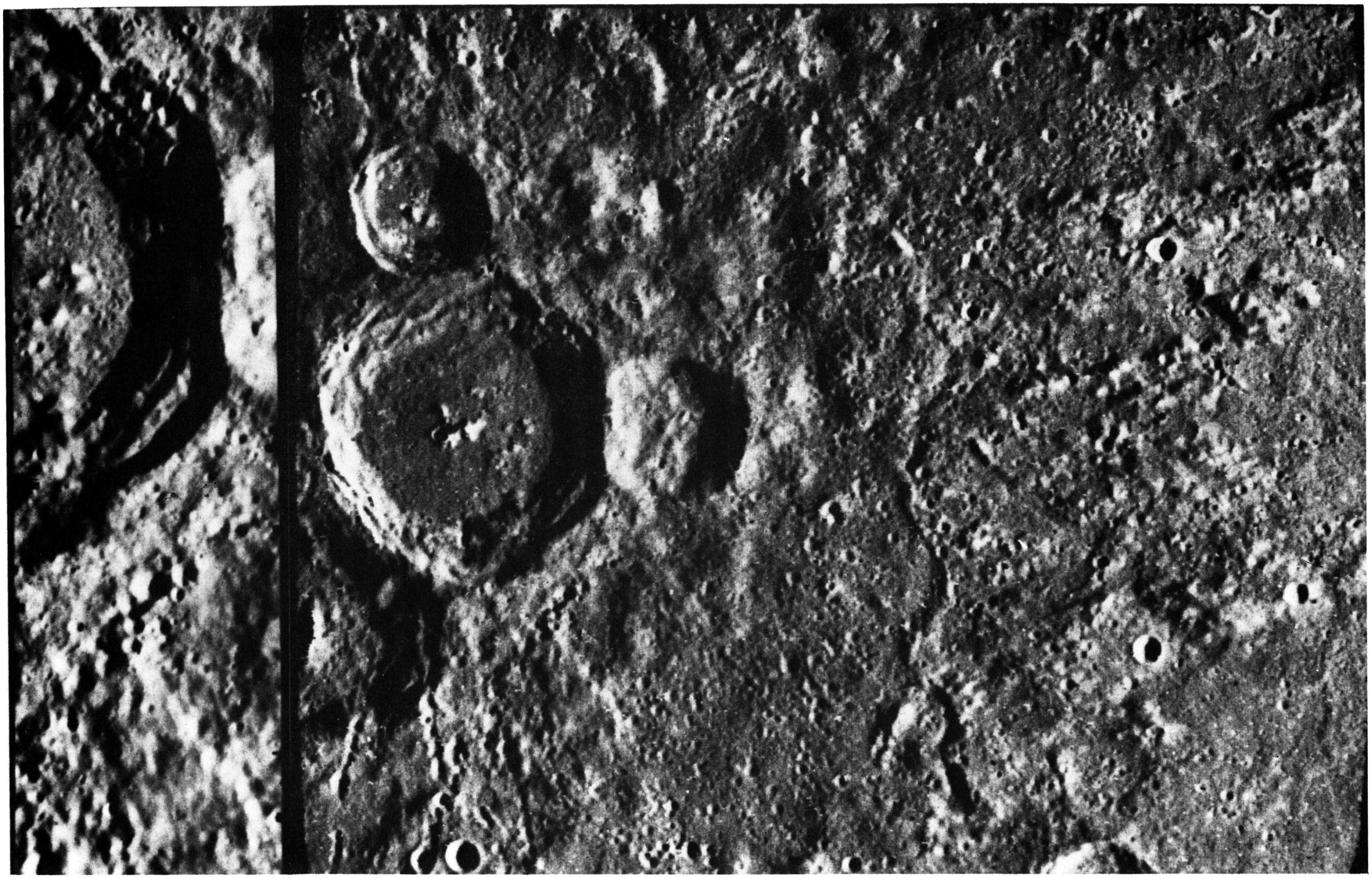

Fig. 12. This composite picture shows some features of Mercury's surface taken nearly a year apart by Mariner 10 during the first and third flyby encounters. The narrower strip at left was obtained on 17 March 1975 and shows an area 37 km (23 mi) wide. It was taken from a distance of 18,600 km (11,500 mi). The right-hand portion of the composite photo shows the same area taken 176 days earlier, on 29 March 1974 at a range of 33,300 km (20,700 mi). This scene, which is 279 km (173 mi) across on the right-hand strip, shows much terracing on the crater wall along with some degradation by secondary impacts from a nearby crater.