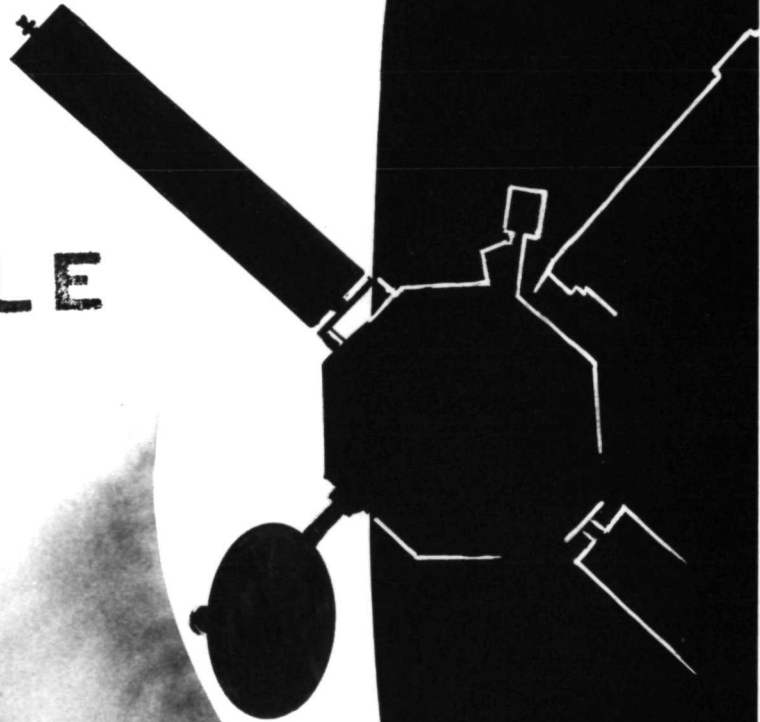


# MARINER VENUS MERCURY 1973

N74-10778

**CASE FILE  
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NATIONAL AERONAUTICS AND SPACE  
ADMINISTRATION

CONTENTS

1. Inner Planet . . . . .	1
2. Ticket to Ride . . . . .	5
Launch Vehicle . . . . .	5
Mariner Spacecraft . . . . .	6
Tracking and Data System . . . . .	8
Mission Operations . . . . .	9
3. Night Train . . . . .	11
Look Homeward, Mariner . . . . .	13
Duet With the Comet . . . . .	14
4. Transfer Point: Pressure-Cooker Planet . . . . .	17
Secret Planet . . . . .	17
The Venus Parade . . . . .	19
Science at the Corner . . . . .	20
5. Destination Mercury . . . . .	23
Broiled World . . . . .	23
First Flyby . . . . .	25
6. Running Free . . . . .	27
Round Trip . . . . .	28
Relativity . . . . .	28
Souvenirs . . . . .	29

MARINER

VENUS

MERCURY

1973

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Technical Memorandum 33-657

This document presents work carried out by and for the Mariner Venus/Mercury Project Office, JPL, under contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration. Written by James H. Wilson, designed by Frank J. Licher. Set on the IBM Composer by Louise Beard.

JET PROPULSION LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA

October 15, 1973

Cover: Spacecraft enters Mercury's shadow.



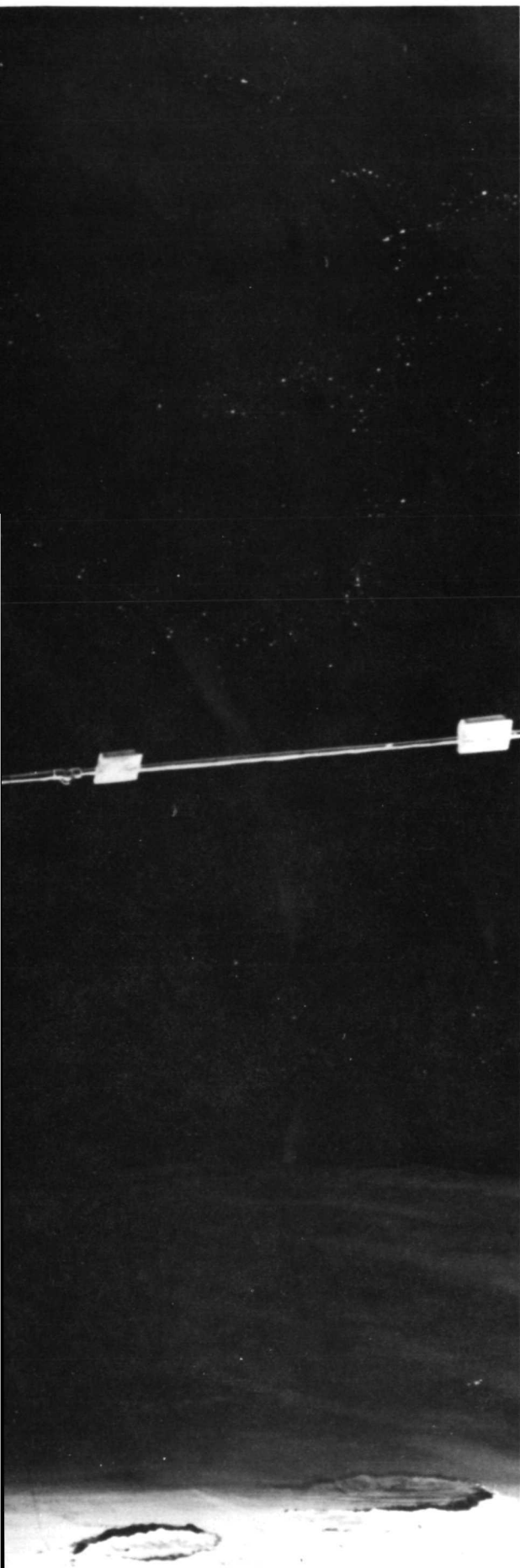
# 1. INNER PLANET TOUR

THREE PLANETS, FIVE MONTHS, \$98 MILLION! No travel agency can yet offer such a packaged winter tour to anyone. But seven scientific teams are taking a tour from the Earth-Moon system by way of Venus to Mercury, by proxy, in late 1973 and early 1974, with options on a midflight survey of Kohoutek's Comet and a return trip to the planet Mercury as added attractions.

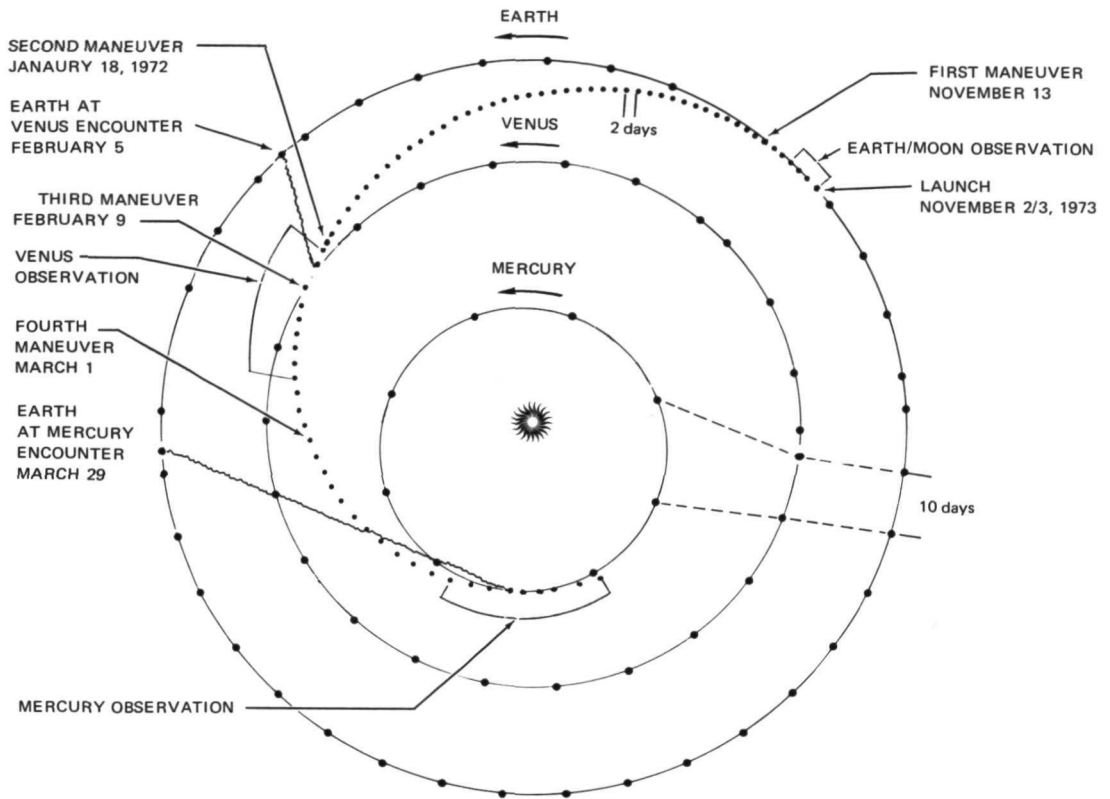
This mission, part of NASA's continuing scientific exploration of the Solar System, will be the tenth flight in the Mariner Project series conducted by Caltech's Jet Propulsion Laboratory. The spacecraft is propelled, like all the Mariners since Number Six, by an Atlas/Centaur rocket system built by General Dynamics/Convair for NASA's Lewis Research Center and launched by a composite team at the John F. Kennedy Space Center. Modified greatly from earlier Mariners, the spacecraft was built by The Boeing Company in Kent, Washington, for JPL. It is tracked on its three-planet tour by the worldwide NASA/JPL Deep Space Network and controlled by a project team from JPL's Space Flight Operations Facility in Pasadena, California. Like each earlier interplanetary Mariner, this vehicle leaves behind its entire crew of more than a thousand scientists, engineers, technicians, and other essential people.

Though it is a fascinating object of study to the planetologist, Venus is part of this Mariner itinerary primarily for another reason: the planet's gravitational field can provide a necessary extra stage of propulsion, enough to reach Mercury economically. The spacecraft must be aimed very precisely for its planetary flyby so that, on leaving Venus, its speed is reduced and its direction pulled sunward so that it falls the rest of the way to the innermost planet rather than coasting back out in the direction of Earth's orbit. The first stage of ballistic flight, to Venus, takes about three months; the second, to Mercury, about two.

The technique of using one planet's gravitation to reach the next receives its first test in Mariner Venus/Mercury 1973. Worked out in the early 1960s by Clarke and Minovitch, it was at the core of the dramatic Outer Planet



Left, Mariner spacecraft coasts past Mercury  
(Boeing Company painting)



Mariner 1973 mission plan calls for three planetary encounters, four maneuvers

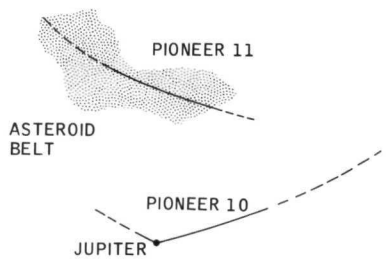
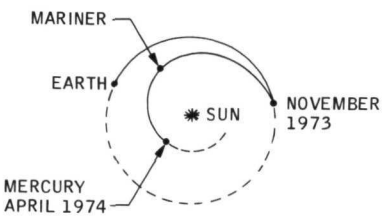
Grand Tour proposal, in which five planets were to be linked together in a single flight. It will be essential to the Mariner Jupiter/Saturn 1977 mission. The method requires the coincidence of the various planets along the great spiral travelled by the spacecraft at the correct times; for all five outer planets, this occurs only every 130 years, but for Venus and Mercury it happens about every dozen years; therefore 1973-74 is a good opportunity for this flight.

Among the scientific opportunities offered by this particular multiple mission, perhaps the greatest is the direct comparison, using the same instruments over a short interval of time,

between Earth and Moon, Venus, and Mercury. Our planet and Venus are about the same size and mass (though vastly different in atmosphere and surface conditions); the Moon and Mercury are also thought to be a comparable pair. Mercury, of course receives its first close-up investigation from this flight.

A similar comparative investigation of solar activity by instruments immersed in it, all over the solar system, may be conducted. As the Mariner spacecraft travels from Earth to Mercury, two Pioneer Jupiter spacecraft are flying out beyond the asteroid belt and the Interplanetary Monitoring Platform (IMP) is in Earth orbit. Similar magnetometers, plasma

detectors, and cosmic radiation telescopes on these spacecraft, as well as the many types of instruments in Earth's laboratories, will work together in mapping the solar wind, magnetic storms, and flares as they emerge from the Sun and flow outward through the planetary system.



Mariner/Pioneer collaboration prospects

A third feature of coordination in this mission is between the different scientific instruments aboard the single Mariner

spacecraft. More than a decade's swift progress in planetary and space science, including the experience of preparing and flying spacecraft and scientific instruments in Earth satellites, the lunar program, Pioneer and Mariner missions, have led toward a unifying vision of the phenomena of the Solar System, coupled with instrumental capabilities which support multi-media investigations of the nature of a planet and its environment. Mercury and Venus will be subjected to this searching investigation in early 1974 by many kinds of scientists, from geologist to astrophysicist, using every type of instrument from TV telescopes to radio transmitters.

Everything we learn about another planet is compared and contrasted with what we already know about this planet; everything we learn about the Sun is in itself knowledge of our world. Mariner Venus/Mercury 1973 is designed to add one new planet, Mercury, to the comparison; to add greatly to what we have learned in previous Venus missions by the US and the USSR, and to study the Sun's behavior from a new, close perspective. In addition, it pioneers a new technique of reaching more distant planets, and increases our experience in interplanetary exploration. This Mariner flight is a new step in our continuing journey to knowledge.

**INNOVATIONS IN THIS MISSION**

- First Mercury flyby mission, first close-up pictures of clouds of Venus, first survey of solar plasma as close as Mercury.**
- First use of gravity-turn mission at one planet to reach another.**
- Direct comparison with identical science equipment between four planetary bodies: Earth, Moon, Venus, Mercury.**
- Support of coordinated observation of solar wind and flares at 0.4, 1.0, and 5.2 astronomical units from Sun.**
- First interplanetary X-band (8500-megahertz) tracking.**
- Highest interplanetary data rate, permitting real-time interplanetary television transmission as normal mode.**
- Most rigorous interplanetary navigation requirements, supporting gravity turn at Venus and repeated Mercury flyby.**



## 2. TICKET TO RIDE

The means and mechanisms by which the scientific potential of Mariner Venus/Mercury 1973 is turned into real achievement and new understanding of the world around us include some complicated machines which had to be built, pre-existing computers and other general-purpose equipment which had to be programmed and scheduled, and complex and difficult operations which had to be designed, learned, and rehearsed. The key to all of these was the mission design which binds them together.

The Mariner mission design for 1973 prescribed that early in November the spacecraft and launch vehicle systems, having been assembled, tested, and qualified for the mission, would be launched from the John F. Kennedy Space Center, Florida, in such a way that the spacecraft falls around the Sun in a ballistic path passing through a selected aim point above the planet Venus at a precise time. The preferred time of launch was determined to be in the middle of the night, East Coast time, between November 2 and 3. The corresponding preferred time of arrival at Venus worked out to be February 5, 1974. The spacecraft would then reach the vicinity of Mercury at 2000 GMT, March 29, as afternoon stretches across America. Actually, the Mercury pass defines the events leading to it. Its characteristics were determined from the various observations the scientific experimenters want to make there, for the Mercury portion of this scientific voyage is paramount. The capability of the Atlas/Centaur launch vehicle, and the mass of the Mariner spacecraft (partly determined by its passenger list of scientific equipment) form a crucial part of these calculations and decisions. In addition, the capability and geometry of the Deep Space Network stations around the world, and the capacity of the telecommunications system between the Mariner spacecraft in flight and the controllers and scientists on Earth affect the design of the venture. Finally, the operational ability of the ground-based complex of human beings, computing systems, and procedures to handle and act upon the information sent to them from their machine in space defined what could be done and how it would occur.

These four components which carry out the mission are called the systems of the Mariner Project. Though each is focused upon machines of different kinds, to various degrees, these systems consist of human beings, their skills, tools, and creations.

### Launch Vehicle

Atlas/Centaur is the name of a large, powerful, multi-stage rocket vehicle, earlier versions of which delivered seven Surveyor Landers to the Moon and three Mariner spacecraft to Mars, as well as putting various large unmanned machines in Earth orbit. The launch vehicle consists of several rocket engines, many tons of kerosene-like fuel, liquid oxygen, and liquid hydrogen in thin-walled stainless-steel tanks, structural members and

#### ATLAS/CENTAUR CHARACTERISTICS

**Total length: 36 m (117 ft)**

**Launch weight: 147,000 Kg (162 tons) plus spacecraft**

**Atlas D Stage: two booster engines, one sustainer, burning RP-1 in liquid oxygen, total thrust 1.92 million newtons (431,000 lbf).**

**Centaur D-1a stage: two 67,000-newton (15,000-lb) thrust engines, burning liquid hydrogen and liquid oxygen; radio-inertial guidance.**

insulation panels, and a highly accurate guidance system. It has been in service for ten years, and is built by General Dynamics/Convair Astronautics in San Diego, California, a company which once made flying boats and Liberator bombers for World War II.

Because of its lightweight design, the Atlas stage needs to be full of fuel and oxygen to stand up in Earth's gravity; when it's empty, the rocket has to be held up by a sling, or blown up like a balloon with compressed air. Yet when it's in action, the rocket reaches an acceleration of 5.76 g's in 146 seconds, and could deliver its spacecraft to the interplanetary transfer point in 11.7 minutes. For this mission,

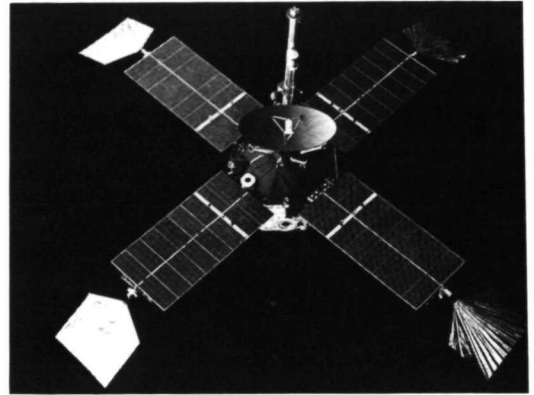


however, the upper stage coasts almost halfway around the Earth in 34.5 minutes, where the final push is delivered over Earth's sunny side.

The Atlas/Centaur is launched from Pad 36 at the John F. Kennedy Space Center, which was built for it in 1962. It flies out across and above the South Atlantic, while stations on small islands and instrumented aircraft track its signals and monitor its progress. As the Centaur stage and the spacecraft rise higher above the Earth, they seem to turn around in the sky, until they are passing from East to West with the Sun. By this time they are out of range of the Eastern Test Range stations, and it is only the big antennas of the Deep Space Stations in Australia, Spain, and California which will follow the Mariner tracking and telemetry signals from horizon to horizon.

### Mariner Spacecraft

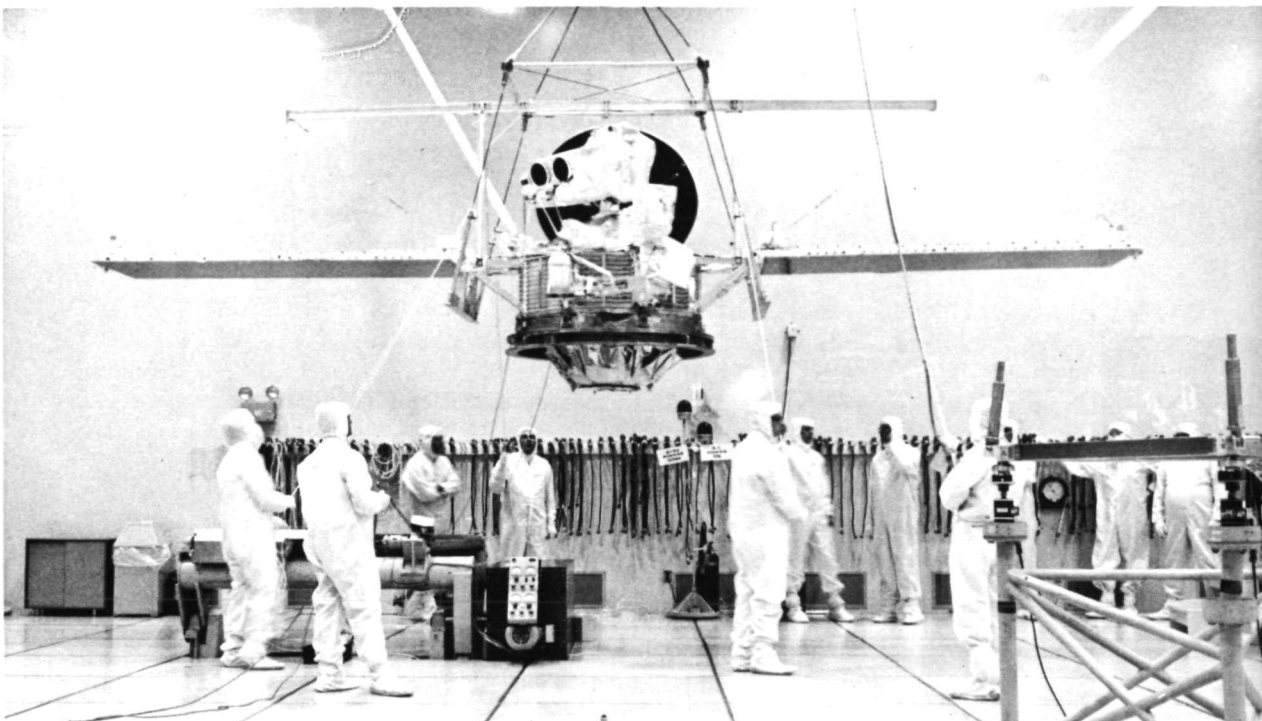
The machine which is actually making the three-planet tour is, in its design, a mixture of old and new elements. Its ancestor is Mariner 4, the first spacecraft to conduct a scientific Mars mission, which sent back pictures and other scientific information in mid-1965 and operated in orbit for a total of three years. The spare spacecraft from that mission was converted for a Venus flight in 1967, when it



Mariner 4 Mars spacecraft, 1964-65

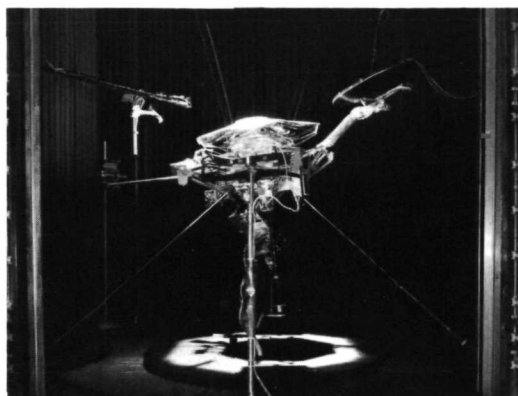
conducted dual-frequency radio probes of the atmosphere and sampled the solar-plasma interaction with Venus. Two new Mariner spacecraft, built on the model of Mariner 4 but much heavier and carrying a sophisticated scientific complement, devoted exclusively to planetary investigation, flew by Mars in 1969, analyzing the planet's atmosphere and returning pictures of broad swaths near the equator and the South Pole. A modified version of the 1969 design, with a large propulsion system and a similar planetological scientific instrument group, was placed in orbit about Mars in 1971, where, in a year of operations, it took more than 7000 images of the surface, together with other scientific information.

Below, Mariner Venus/Mercury spacecraft weighed and balanced at Boeing plant



But the new Mariner spacecraft faces drastically different challenges. Where a spacecraft going to Mars needed four broad solar panels to capture enough solar energy to operate its electrical equipment, the Venus mission offers a surplus of sunlight and heat, which grows to painful excess as the machine approaches Mercury. All the skills of the designer must be engaged to deflect heat, rather than husband it. Both Mariner 2 and Mariner 5 are believed to have expired, after completing their Venus encounters, from overexposure to the Sun's output. This new Mariner must keep cool all the way in to Mercury, where the Sun is five times as hot as at Earth; it hides behind a white fabric umbrella, made of the same "beta cloth" that covers astronauts' suits. Safe in the shade, the spacecraft body is quite cold, though the exposed solar panels are quite hot.

There has been a striking increase in spacecraft communication rate over the dozen years of the Mariner Program. These spacecraft have used digital telemetry, a method like Morse Code which can punch through distance and galactic noise, partly by lowering the rate at which data are sent as the distance increases. The first three missions used a 33-1/3 bit per second rate part way, and 8-1/3 bits per second at the planet. The succeeding Mars missions, by large improvements both at the spacecraft and



Thermal test in JPL solar simulator

in the ground receiving systems, increased the rate for planetary data return to 16,000 bits per second. In the Venus/Mercury mission a rate of 117,000 will be used at Venus; and at least 22,000 at Mercury. This permits the scientists to obtain much more information, as well as more "live" pictures, during the short period the spacecraft spends near each planet.

Extremely accurate flight is required in this mission – reaching Venus at the correct place, time, speed, and direction to be thrown toward Mercury, then approaching Mercury with the same kind of accuracy to perform both the scientific investigation planned and to return to this planet 176 days later. Four corrective thrusting maneuvers are planned before the first

#### MARINER'S SCIENTIFIC EXPERIMENTS

Experiment Team Leader	Instrument	Purpose
Bruce C. Murray, Caltech	TV Cameras (2)	Planet surface, cloud, star, comet viewing, colors and ultraviolet.
Herbert S. Bridge, MIT	Plasma Detectors (2)	Solar wind measurements, planetary radiation belts, etc.
Stillman C. Chase, Santa Barbara Research	Infrared Radiometer	Temperature measurements and thermal mapping.
Norman F. Ness, Goddard Space Flight Center	Magnetometers (2)	Planetary and space magnetic field measurements.
John F. Simpson, University of Chicago	Charged Particle Telescopes (2)	Survey of higher-energy particles in space (by direction, kind, intensity).
A. Lyle Broadfoot, Kitt Peak Observatory	Ultraviolet Spectrometer (2)	Analysis of upper atmosphere's luminous night clouds, comet, etc.
H. Taylor Howard, Stanford University	X-Band and S-Band Radio Science	Atmosphere properties, space properties, etc.

Mercury pass: one near Earth, to narrow the initial dispersion, another close to Venus to fine-tune the passage through her gravitational field, a third after Venus has changed Mariner's path, and the fourth at the beginning of the approach to Mercury. After the encounter with Mercury, three more maneuvers are expected to ensure that Mariner comes back for a second pass. For each of these maneuvers, the spacecraft is turned until its small rocket engine — pointed at the Sun during the long ballistic cruise — is aimed in a direction calculated to change the path as needed, then the engine burns until the velocity change is completed.

Each of these survival functions — thermal control, communications, and flight accuracy — has been carried out in previous designs, under different conditions, and in varied ways. The flight of Venus and Mercury poses new and more difficult problems in these areas. Mariner's designers have provided for other functions, such as attitude control, equipment packaging, telemetry reporting of engineering performance, structural integrity during the launch, spacecraft computer control, etc., mostly in the ways developed in earlier projects, because this mission is not so exceptional in everything as it is in the thermal control and navigation areas.

## Tracking and Data System

Over a decade ago, in the time of the first Mariners, the Deep Space Network came into being as a ring of great dish antennas located in out-of-the-way sites around the world, capable of following, and communicating with, spacecraft at distances above 10,000 miles from Earth's surface. As Mariner has evolved, so has the complex of tracking, control, and communication equipment which keeps Earth in touch with these deep-space enterprises.

The first of the long-range steerable antennas, with parabolic reflectors 26 meters (85 feet) in diameter, was built in the California desert near Goldstone Dry Lake. Global coverage was complete when matching systems were installed near Johannesburg, South Africa, and Woomera, Australia. Now there are three 26-meter antennas at Goldstone and an advanced antenna system with a 64-meter (210 feet) reflector; one of each size in Australia's Tidbinbilla complex; and three antennas, including one of 64-meter diameter, in Spain. Each station is operated by local contractors and government agencies, and the whole network is managed for NASA by JPL. They have supported Pioneer and Mariner missions as well as three unmanned lunar projects and the Apollo Lunar Landing missions. Mariner

Below, Deep Space Station, Tidbinbilla, Australia, with 26-m and 64-m antennas



Venus/Mercury 1973 is the first Mariner Project to have the advantage of a complete chain of the 64-meter advanced antenna systems, whose sensitive receiving equipment makes possible the high data rates provided for this mission.

The stations are linked together and to their central control point in Pasadena by elements of NASA's Ground Communications System, which uses submarine cables, land lines, radio links, and communication satellite channels to ensure that no data are lost. The system is directed, and its coverage of multiple missions is scheduled, from JPL.

The Mission Control and Computing Complex is a part of JPL's data-processing capability organized to support space flight operations. Partly a spin-off from the Deep Space Network, it provides for machine analysis of spacecraft tracking, converting S-band doppler residuals and ranging information into accurate plots of the spacecraft's position and motion. It also processes engineering telemetry and scientific data sent to Earth from the spacecraft, producing warnings of dangerous situations in the spacecraft should they develop, and various plots, spectra, and image reconstructions. A variety of special programs have been developed in recent Mariner missions, one of the most interesting of which creates a series of line drawings predicting the areas to be covered by television pictures a spacecraft can

take as it approaches its target planet on a prescribed course.

### Mission Operations

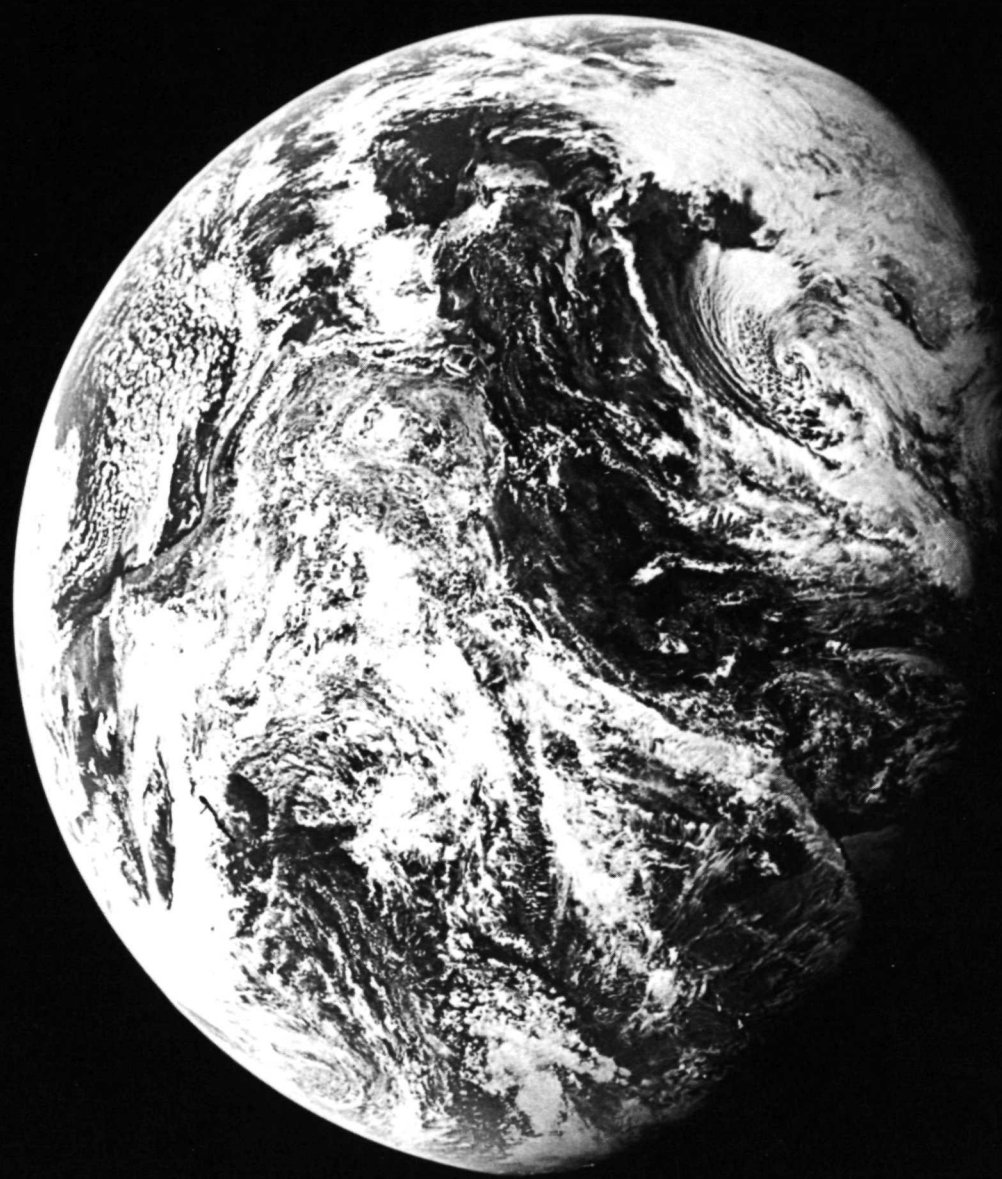
The exact form of what the project actually does with its spacecraft throughout the flight is called the mission operations. The navigation, engineering operations, and scientific work of the remote laboratory instrument called the Mariner spacecraft is the responsibility of an earth-bound crew of about 120 people.

A similar but larger group, operating at and around the John F. Kennedy Space Center, conducts launch operations, and as soon as these are completed less than an hour after liftoff, the Mission Operations takes over.

Mariner's space crew has certain special equipment and many computer programs to work with, but for the most part the operations depend on the crew's skills and training, and the complex plan worked out in detail and carefully rehearsed before each operation is conducted. The actual flight conditions are never exactly as predicted, and surprising events or even failures can occur at any time. In addition, early scientific observations may call for changes in later investigations in the same mission, and it is up to the Mariner mission operators to supply enough flexibility in designs and procedures to accommodate changes in plan as efficiently as possible.



Members of Mariner Mission operations team during preflight test



### 3. NIGHT TRAIN

The major part of the Mariner Venus/Mercury 1973 mission is spent far away from Venus or Mercury. Yet it is no idle time, for what happens in the swift passage by these planets depends on preparatory work done during the two "cruise phases," and the scientific program includes extended instrument operations during the interplanetary flight.

Activities during the cruise phase might be divided into four classes, each engaging the operations crews on the ground, their computing and data-processing equipment, the deep-space communications link, and the spacecraft flying ever farther away. These activities are navigation, engineering, scientific instrument calibration, and scientific observations. Inevitably there is some mixture and interdependence among the operations.

The most crucial requirement of this mission is to reach the planet Mercury. This goal requires an accurate launch, a careful passage through the gravitational field of Venus, and the four small correction maneuvers performed during the flight. The timing of such maneuvers results from an engineering tradeoff: the earlier the maneuver, the less fuel required to make a given change at the target zone; the later the maneuver, the more time beforehand for tracking. Therefore the more accurately the required change is known, the smaller the effect of errors in the maneuver itself. The effort of tracking and calculating, then maneuvering, then tracking and calculating again, moves the spacecraft's actual arrival point close to the desired target, first above Venus and then over Mercury, and occupies Mariner's navigation team during most of the mission.

The next most crucial requirement (really part of the first one) is for the equipment to reach the planets in good condition. Everything should be working. This is the concern of the spacecraft performance team. They must be sure that the instruments and devices are being protected from the heat of the Sun and the cold of space — though generally the space environment is a healthy one for these equipments. Assurance of adequate electrical power is another concern. Maintenance of the

best possible communications with the Earth is a third.

These three factors depend on the spacecraft's maintaining its orientation in space. For this reason telemetry readouts from attitude control equipment occupy many of the time-shared channels in the engineering signal received from the spacecraft. The desired attitude is maintained automatically by cold-gas jets controlled by Sun and star sensors, gyros, and control amplifiers. The bright stars Vega and Canopus serve as angular references.

Most spacecraft operational sequences, including maneuvers, planetary encounters, instrument calibrations, and the like, are controlled by the spacecraft's programmable computer; some operations may also be commanded directly from Earth by radio signals. As more computer memory space is freed during the progress of the mission, and as the times and dimensions of the planetary encounters become more accurately known, the spacecraft operators will re-program these sequences to be sure they will be accomplished as well as possible even if the command link were broken at some crucial time.

Another periodic activity is the preparation and calibration of the scientific instruments for observational use. The magnetometer is calibrated periodically throughout the flight by putting the spacecraft into a slow windmill roll. Magnetic fields present in surrounding space seem to rotate, while those resulting from spacecraft electrical equipment remain fixed in direction relative to the spacecraft sensors. During the rolling, the ultraviolet spectrometer sweeps the sky and is calibrated on the stars. The plasma detectors and charged-particle telescope are also checked at intervals to determine whether they have "drifted" from the known relation of sensed phenomena to signal output. The television cameras can be calibrated during or between operations using a special lens on each filter wheel, but the whole experiment is calibrated early in flight using Earth and Moon as test targets, in operations that constitute special scientific investigations and are described later.

**Launch Weight: 499 kg (1100 lb)**

**Span (panels extended): 7.6 m (26 ft)**

**Radio Transmitter Output: 10 or 20 watts S-Band  
200 mw X-Band**

**Engineering Telemetry: 90 measurements at 2450 or  
33-1/3 bits/sec, programmable selection.**

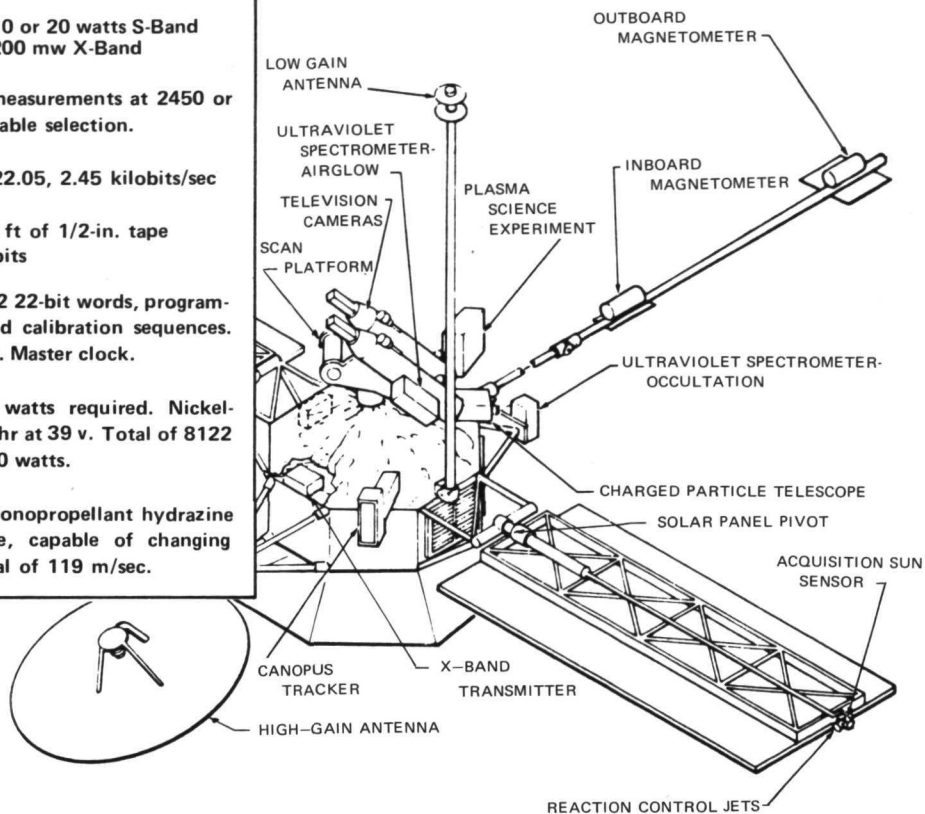
**Science Data Rates: 117.6, 22.05, 2.45 kilobits/sec**

**Tape Recorder: 8-track, 550 ft of 1/2-in. tape  
180 million bits**

**Computer: Memory holds 512 22-bit words, program-  
mable for observation and calibration sequences.  
Fixed maneuver sequencer. Master clock.**

**Electrical Power: 340-490 watts required. Nickel-  
cadmium battery, 20 amp-hr at 39 v. Total of 8122  
solar cells, peak output 500 watts.**

**Spacecraft Propulsion: Monopropellant hydrazine  
rocket engine, restartable, capable of changing  
spacecraft velocity by total of 119 m/sec.**



Mariner Venus/Mercury 1973 spacecraft

The continuing scientific operations which occupy the interplanetary phases of flight have to do primarily with the fields and particles experiments. Mounted on a six-meter-long (20-ft) folding boom, each of the two magnetometer instruments contains three fluxgate sensors to indicate field strength and direction. After leaving the Earth's field, the magnetometer investigates the thin and fluctuating magnetism which emanates from the Sun, borne on the steadily flowing plasma and the irregular, intense streams which rush out from solar flares. It will also help define the plasma's interactions with the planets, and search for evidence of planetary magnetic fields during the planetary encounters, like the Mariner instruments which flew by Venus in 1962 and Mars in 1965 at considerably greater distances.

The charged-particle telescope detects high-energy electrons and light-element nuclei with two devices aimed about 45 degrees from the Sun line, one of them with an additional rear field of view. Its purpose is to monitor solar and galactic cosmic rays and solar-flare particles, and to seek trapped charged-particle belts and plasma/planet interactions at the two target planets. Such structures around Earth have been extensively studied, and a previous investigation of Venus found a relatively weak plasma interaction and no trapped belts.

The solar wind is a great slow spherical river of charged particles which flows out in all directions from the Sun, guided by and carrying along the solar magnetic field. It is usually investigated by spacecraft which immerse in it plasma detectors like the 1973 Mariner's scanning electrostatic analyzer and scanning

electron spectrometer. No previous experiment has ever been closer to the source of the flow than the orbit of Venus; these Mariner instruments will reach out to the distance of Mercury, more than twice as close to the Sun as Earth. It is believed that at this close point the experiment may detect physical processes which occur in the wind as it expands and becomes less dense.

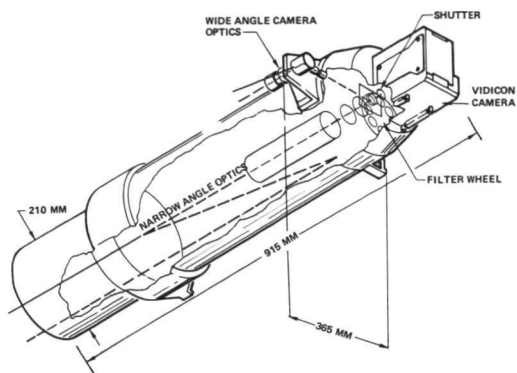
In addition, the ultraviolet spectrometer experiment conducts periodic sky surveys in a search for the interplanetary and galactic sources of diffuse ultraviolet hydrogen and helium emissions. These radiations are blocked from Earth-based surveys by our atmosphere.

### Look Homeward, Mariner

Some of the earliest scientific data acquired by the Mariner spacecraft are planetary in nature. In the first few hours of flight, the cameras are turned on Earth and the Moon, and mosaics of views, rather like those scheduled for the Venus and Mercury encounters, are begun. This approach-in-reverse, in which the planet gradually shrinks in the pictures as the spacecraft recedes from it, lasts for about 3-1/2 days. Several color telephoto-mosaics of



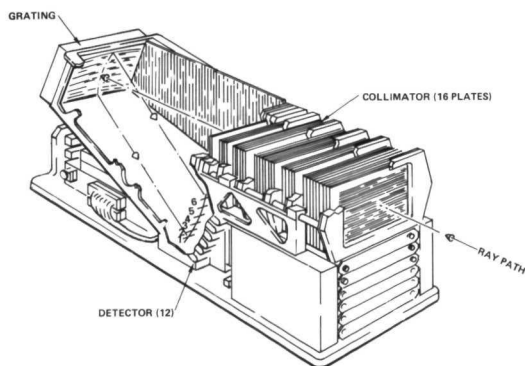
The Moon, photographed from Apollo 8



One of two identical TV telescopes

overlapping narrow-angle images will be taken of the Earth and the Moon, in sequences which serve to rehearse and calibrate for the corresponding activities at Venus and Mercury. The television picture mosaics themselves are unlikely to reveal anything new about the Earth or the Moon, but in conjunction with similar data taken at Venus and Mercury, three and five months later, they may well provide new light in comparative planetology.

The Earth is surrounded by vast, thin, invisible clouds of neutral and ionized hydrogen and helium which trail out toward space in the force of the solar emissions which replenish them. These clouds fluoresce in the ultraviolet light and the ultraviolet spectrometer scans them to determine their extent and structure. In addition, for comparison with Mercury, should that body resemble the Moon in more than size, our satellite's ultraviolet reflecting properties are studied.



Ultraviolet airglow spectrometer

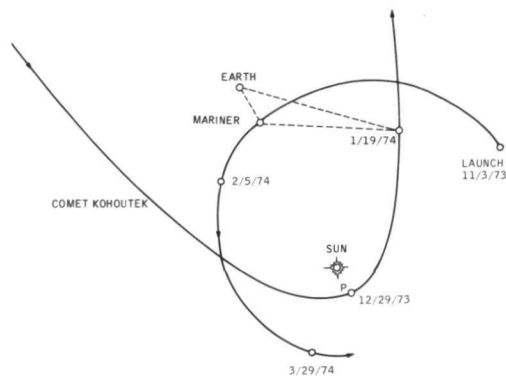


The instruments which will be turned on our Earth-Moon system early in the Venus/Mercury flight are mounted on a scan platform or turret in the center of the shaded side of the spacecraft in a Mariner style maintained unchanged in flights to Mars since 1964. They are placed in such a way that they can never, so long as the spacecraft maintains its proper attitude, see the Sun, which would destroy them. The two identical television cameras and airglow ultraviolet spectrometer point in almost the same direction, which is controlled by the spacecraft computer.

Each television instrument consists of a vidicon image tube and two optical systems. The main telescope is a 1500-mm, f/8.43 Cassegrain reflecting telescope, something like the large Questar or a super-telephoto, with a field of view only a fraction of a degree wide. It is backed by an eight-position filter wheel with clear and color sections, UV-polarizing, UV-blocking, and UV-passing filters (for cloud studies especially), the calibration lens, and a periscope mirror to the wide-angle optics. This auxiliary wide-angle system, mounted like the finder scope on an amateur astronomer's instrument, is a 62-mm f/8.5 refractor, with a field of about 8 x 10 degrees. It is used when the planet is quite close, and to cover a large area on a single frame. The image provided by this complex optical system is about the size of a 16-mm movie frame, but it is presented on the faceplate of a vidicon tube where it is registered electrostatically and read out by an electron beam in a period of 42 sec. Shuttering alternately, the two cameras deliver approximately three pictures every two minutes; these can be transmitted directly to Earth from at least as far as the Venus encounter, recorded for playback at a lower rate, or edited to partial pictures for direct return at the lower rate when distance makes communication more difficult. The high rate of communications - from Venus, 4-1/2 times as large as the data rate Mariner 9 used to return its Mars pictures - and two cameras permit the extensive multicolor coverage of flyby targets required by all parts of the mission.

## Duet with the Comet

Mark Twain used to remark that he came in with the comet, and expected to go out with it; in fact his life was spanned between the last two appearances of Halley's Comet, which visits



Mariner - comet geometry

our skies every three-quarters of a century. Mariner Venus/Mercury lifts off Earth about the time the newly discovered Comet Kohoutek passes the orbit of Mars on its way in toward the Sun, but it will be only two weeks past Venus when the comet reaches that distance on its way out again. The spacecraft's camera cannot peer around the sunshade and glimpse the comet until mid-January, when the two travellers are 100 million kilometers (over 60 million miles) apart, about as close as they will ever be and 20% closer than the comet can come to Earth.

Earth-based observatory telescopes are far more powerful than Mariner's, and the Skylab satellite can bring more and larger instruments to bear on the comet. But Mariner can observe Kohoutek 24 hours per day, never eclipsed by the Earth nor occluded by our atmosphere and weather. Even Skylab must look through the Earth's extended hydrogen corona, while Mariner's cameras and ultraviolet spectrometer scan unimpeded through interplanetary space to view and analyze the comet's nucleus, coma, and invisible corona.

Only the turret-mounted airglow spectrometer can scan about the sky, analyzing interplanetary gases, Earth, and the comet. An

additional instrument fixed to the spacecraft body points in the direction of the Sun, and will be used principally to observe the filtering and scattering of ultraviolet sunlight by Mercury's (assumed) atmosphere when the spacecraft flies into the planet's shadow. The airglow instrument cannot look any closer than 53 degrees from the Sun. It has an array of collimating baffles, whose slits restrict the field of view to a rectangle 3.6 degrees long, 1.2 degrees wide, and a concave diffraction grating which spreads the extreme ultraviolet spectrum (300–1700 Angstrom units, whereas visible light runs from 4000 to 7000 Angstroms in wavelength) out across 12 detectors situated to measure the intensity at critical frequencies. The occultation instrument has four detectors. The scanning instrument detects radiation emitted by hydrogen, helium, argon, oxygen, neon, carbon, and other atoms, together with indications from certain molecular gases. It serves as a remote gas-analysis system for

materials illuminated by sunlight, and its principal purpose is the study of planetary atmospheres.

Two weeks after the comet-observing opportunity, the Mariner spacecraft begins its approach to Venus. Though by this time it has travelled more than 146 million miles from launch, and sent back to Earth hundreds of thousands of scientific measurements including about 1200 television pictures, the largest tasks and most difficult times still lie ahead. The solar panels are delivering more electrical power than the spacecraft needs, and have already been tilted slightly off the Sun to reduce heat intake. Between Venus and Mercury they will be tilted still further – otherwise the very solder in their circuits might melt. Mariner is entering a critical period in its mission and for its survival. But this spacecraft has been carefully designed to stand up under the close-range pounding of the fierce star that turns Earth's skies blue every morning.



Venus as if seen from approaching Mariner (actually photographed from Table Mountain Observatory)

## 4. TRANSFER POINT: PRESSURE-COOKER PLANET

Our planet's atmosphere is clearer than that of Venus, and more cloudy than that of Mars; the advantage over both is that we can breathe it. Another benefit we have over Venus is that we can see the stars some nights, though not so often nor so clearly as if we were on Mars. All the stars, with a few exceptions, rise about four minutes earlier each night than the previous night, in an annual repetition which holds its spherical pattern time out of mind. The wandering exceptions have long been known as planets – for about four centuries we have known they were not stars – which weave complex paths among the constellations of the zodiac.

Two of them never escape the Sun into the night sky proper: Venus and Mercury. They shuttle back and forth between being evening and morning stars: Venus wanders a little more than 45 degrees, or about three hours from the Sun at maximum. The evening before Mariner takes off for Venus, its target planet is visible as a bright evening star; the ultimate target, Mercury, is much lower in the sky at sunset, and much less bright.

During the course of the Mariner mission, Venus will swing across in front of the Sun to become a morning star at maximum elongation (angular distance) a few days after the spacecraft flies by Mercury for the first time. It will not pass directly in front of the Sun, as seen here – this rare transit last occurred some 90 years ago and is not due again until 2004. The Mariner spacecraft itself goes through a similar evolution in our skies, although it's "visible" only to sensitive tracking antennas: immediately after launch it slips out to the east of the Sun, and remains in the evening star or afternoon position until mid-January, when it crosses over to the north; at Venus encounter the two bodies are about 20 degrees ahead, or west, of the Sun in earthly skies.

From the target planet it would look completely different. Mariner comes sneaking up out of midnight, like an invisible meteor, streaks across the evening sky toward day, crosses in front of the Sun half-an-hour later, and recedes into the noontime sky.

### Secret Planet

The planet Venus is perpetually covered in bright reflecting clouds, at a level some 75 kilometers (48 miles) above the surface. Below this layer, the atmosphere, consisting predominantly of carbon dioxide, grows steadily thicker until it reaches a pressure 90 times that of the air we breathe. About 70% of the sunlight bounces off the cloud deck, and most of the remainder is absorbed or bent around the lens-like dense gas below. As a consequence we cannot see the surface. Upon this mystery fantasies have been built for a century or more. Venus was depicted as a primordial planet of swamps and dinosaurs, or fertile rain forests, or duned, wind-swept deserts, according to various of these. It was seldom entirely hostile to life as we know it however, until recent times, when the conjunction of advanced Earth-based instruments and early spacecraft made it difficult to believe that the surface temperature could be much cooler than about 600–700°F, at which, in our environment, paper will catch fire and electronic solder melts.

Venus was quite seriously believed to be a young and primitive planet relative to Earth, while Mars was old and worn out, until the mid-to late 1960s, when comparative atmospheric studies, and other considerations, prompted scientists to suggest that the reverse was true: Venus, taking in more solar energy and maintaining a much higher temperature because of its "greenhouse" atmosphere, had lived up its planetary existence quickly, while Mars, distant and cold, was just beginning, and might be continuing, planetary evolution. The latter view was firmly established by the Mariner 9 discovery of a single great rift valley and several great volcanoes on the otherwise cratered (and therefore primordial) red planet.

At the same time Mars was being mapped from an orbiting spacecraft, however, another technique was penetrating the clouds of Venus to produce detailed radar views of its surface. Surprisingly, there were vast, shallow craters, somewhat resembling those on the Moon and most of Mars. It is generally agreed that these

scars of meteorite bombardment were made billions of years ago, during the final stages of formation of the planet.

The Moon and Mars, changed little since that time, still show these scars. But Venus? How could the ancient circular marks survive 3,000 millennia of geological change and evolution, heat, and the formation and hurricane violence of an atmosphere 90 times as great as ours?

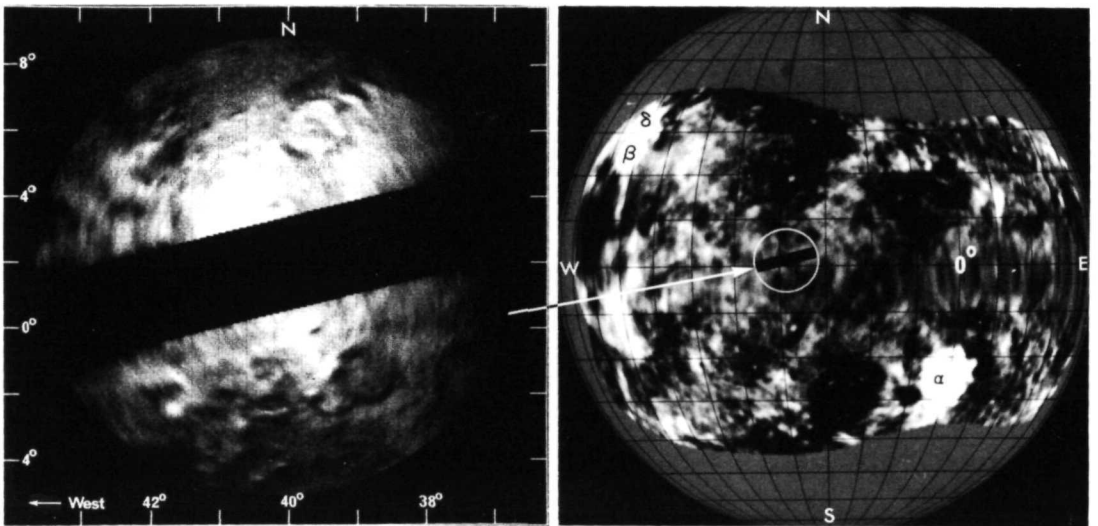
Rather than wrestle with what seems an unanswerable puzzle, let us see how this new evidence came to us. It is part of a sophisticated long-lasting investigation which continues during Mariner's 1973-1974 mission.

The investigation of other planets by radar began about the same time as space exploration; scientists in several countries were active in this field by the early 1960s. Following the initial observations of Venus and other planets, the experimenters measured range and speed of the target planets. These values helped to correct the ephemerides, or tables of position and motion of the planets. Then with the development of more powerful transmitters, larger and more precise antennas, more sensitive and nearly noise-free receivers and amplifiers, and more ingenious computer techniques for analyzing the returned signals, the investigation broadened.

Radar astronomy uses the same measurements as deep-space tracking: frequency shift in a returned signal, and the duration of the round trip. From the latter we derive the distance from the radar site to the object of interest; from the former, the relative velocity. Because of the similarity, the NASA/JPL Deep Space Tracking Station at Goldstone, California, has been one of the pioneer facilities in planetary radar astronomy, and JPL's Richard Goldstein one of the principal investigators in this field.

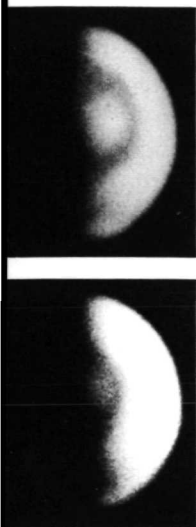
Because of its spherical shape, various parts of a planet are at different ranges from the investigating antenna. Because of its motion — especially daily rotation — different parts have different velocities relative to the antenna. It became possible, then, though very difficult, to sort out the returned radar signals according to the location of reflecting surfaces. At interplanetary distance it is impossible to sort them by angle as is done visually: the angles are too small.

The surface of Venus being inaccessible to any other kind of viewing, it received a large share of radar probes. The period of rotation was determined, first from doppler velocity measurements, then from the tracking of recognizable surface features. It was



1972 radar closeup of Venus' surface, with earlier radar map

surprising: 243 days long, in a direction opposite to that observed for Earth, Mars, and the other planets. Astronomers observed that cloud features visible in ultraviolet light rotated in a period of four days.



UV photos made 4½ hr apart

#### VENUS

- Radius: 95% of Earth's
- Mass: 82% of Earth's
- "Year": 61% of Earth's
- Solar "day": 127 Earth days
- Mean distance from Sun: 75% of Earth's
- Surface gravity: 91% of Earth's
- Surface atmospheric pressure: 90 times Earth's
- Surface temperature: about 700°C

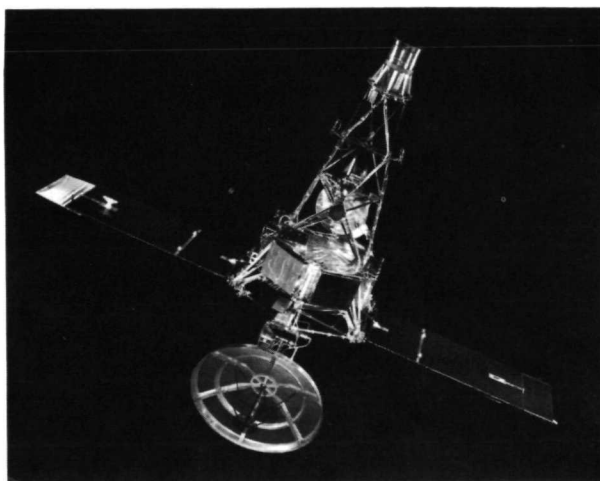
At the same time as these developments, other kinds of Earth-based observation continued, and the United States and the Soviet Union sent spacecraft to the planet Venus. A gas spectrometer, placed at the focus of a telescope, can indicate not only the presence but the quantity of certain constituents of a planet's atmosphere. The quantitative data are difficult to interpret and are sometimes controversial among scientists, and the qualitative survey is hampered by the contamination from Earth's atmosphere and the fact that some gases are not visible to such instruments; but Earth-based spectroscopy remains a valuable tool in planetary research. That carbon dioxide was a constituent of Venus' atmosphere was discovered years ago; it is the major constituent (over 90%) in fact. More recent observations have concentrated on the dynamics of the atmosphere above the cloud layer. A series of infrared spectral investigations made at JPL's Table Mountain Observatory in the Fall of 1972 by Louise Gray Young and associates discovered regular fluctuations in the CO<sub>2</sub> absorption which

suggest that the reflecting clouds may move up and down as much as a kilometer on the four-day cloud-rotation cycle.

#### The Venus Parade

Because launch opportunities for missions to Venus occur every 19 months, there have been many attempts to fly spacecraft to or past this planet since 1960. Most of these (all the successful missions) have been in the US Mariner and USSR Venera programs.

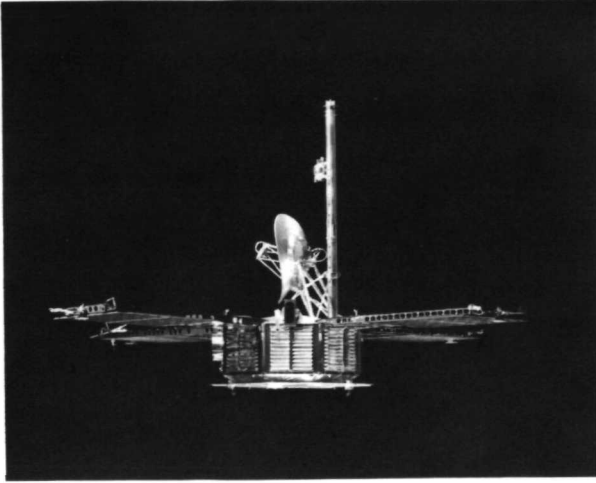
Two of the three Mariners designed to fly past Venus, examining radiation from the planet and sensing fields and particles in its vicinity during 1962 and 1967, achieved their



Mariner 2, Venus, 1962

objectives. The Soviet Union has launched in every opportunity since that of early 1961, apparently hitting the planet with Venera 3 in 1966, but the first Venera to return data from the planet arrived in October 1967 and the first to operate a landing capsule on the surface, Venera 7, was in December 1970. Venera missions conducted a variety of experiments, chief among them (on the entry probes) being direct chemical analysis of the atmosphere and, in Fall 1972, a photometer which showed how much light actually reaches the surface.

Experiments in the Mariner projects and the earlier Venera atmospheric probes, confirmed and extended to the surface by Venera 7, indicated a very high surface



Mariner 5, Venus, 1967

temperature  $-475^{\circ}\text{C}$  or about  $900^{\circ}\text{F}$ , from Venera 7 – and a pressure of 90 atmospheres. Composition of the atmosphere is estimated at about 95%  $\text{CO}_2$ , a few percent nitrogen, a trace of oxygen and inert gases (not susceptible to chemical reactions), and a small amount of water vapor.

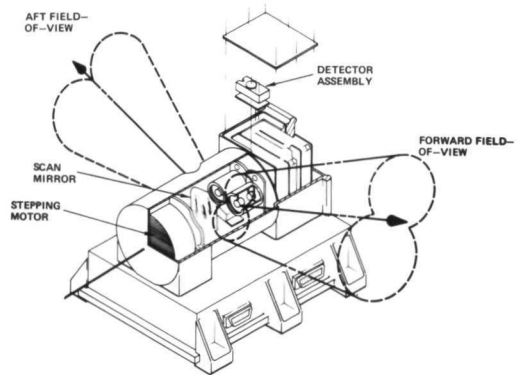
Mariner 5, which flew 10,150 kilometers from the center of Venus or about 2500 miles above the surface, sent its two-way S-band radio signal (and a one-way UHF/VHF dual-frequency probe) through the atmosphere as it was occulted from Earth behind the planet, detecting the ionosphere above both day and night sides, and reading atmospheric pressure down to an altitude of about 30 kilometers (19 miles). It was estimated that nearer the surface the radio beam would be bent into a circle around the planet by the lens-like atmosphere. This earlier Mariner also searched for evidence of a planetary magnetic field and trapped radiation belts, flew through Venus' plasma shock wave, and detected the planet's atomic hydrogen corona and a night-side airglow with its ultraviolet photometer.

Gathering the rapidly growing results of observations from Earth, spacecraft missions, and comparison with other planets, astronomer Carl Sagan suggests that Venus resembles legendary hell. Sunlight is reduced to a diffused and pervading reddish glow which never

completely darkens in the nine-week-long night; the atmosphere is oppressive, hot, and choking.

### Science at the Corner

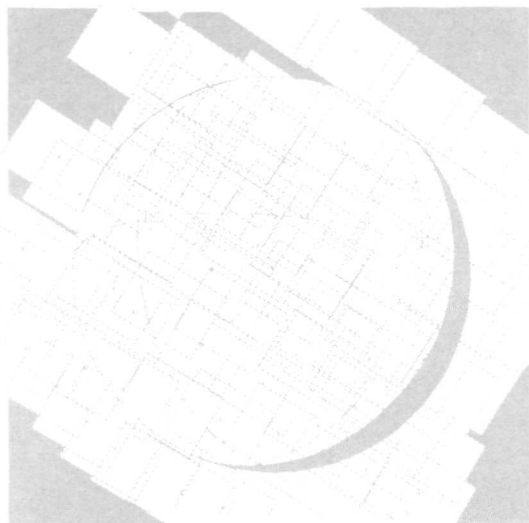
Notwithstanding its interest to the planetologists, Venus serves this Mariner mission primarily as a way station to Mercury. The spacecraft approaches the planet from the night side, its cameras blocked by the sunshield until a few minutes before the closest approach at about 5000 km (3100 miles) altitude. An infrared radiometer sweep across the planet,



Mariner's long-distance thermometer

through the midnight meridian into the sunlit side, occupies the 20 minutes before closest approach.

Television surveys of the night side, night-day terminator, and sunlit clouds, and matching UV spectral measurements are returned to Earth in real time during the 15 minutes or so before the spacecraft is occulted by Venus. Then, while pictures and other data are recorded for subsequent return, the radio switches to a low-data, high-power mode, and the antenna tracks through a carefully calculated series of angles designed to keep the S-band and X-band link with Earth working as long as possible through the period (less than half-an-hour) that Earth is out of sight. The refracted beam can thus be followed much further, and the properties of the atmosphere studied longer and to lower altitude than if the antenna were fixed to the line of sight.



TV frame coverage of Venus, 10-12 hr after closest approach, will make a multi-color "mosaic" of the planet

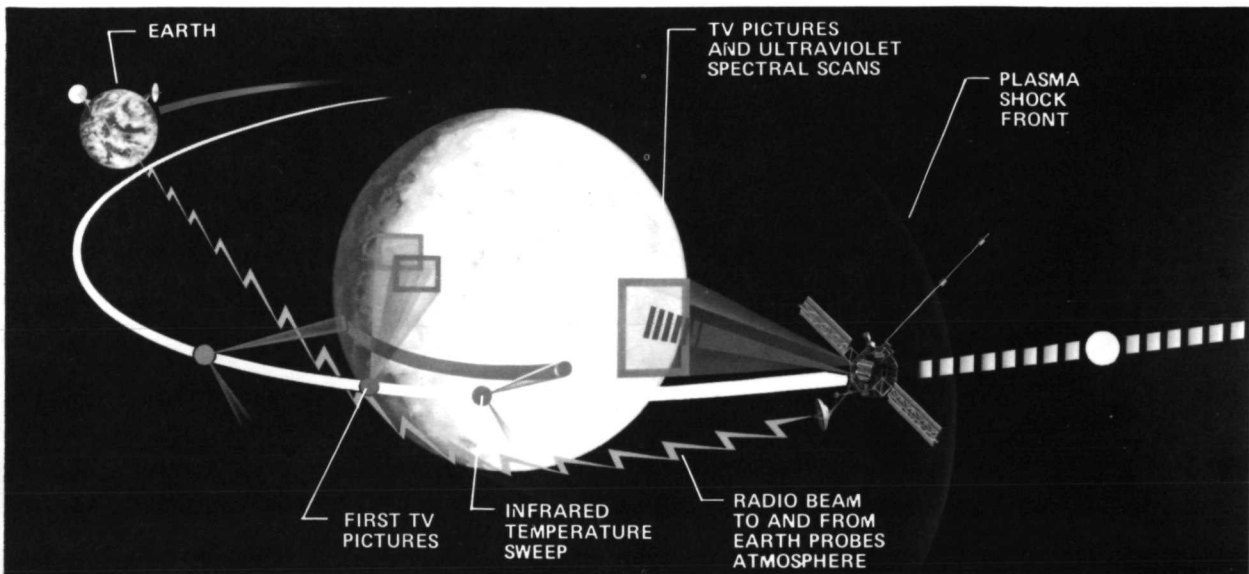
While it's still hidden, the spacecraft flies out through the front of the plasma shock wave created by the planet and its ionosphere. This will show a flurry of changes in the plasma, charged-particle, and magnetic-field instruments, which should settle down soon after to the purely solar levels of activity as seen earlier before Mariner flew into the plasma "wake" of Venus.

By now the spacecraft is out from behind Venus, and can revert to the 117,600 bit-per-second telemetry rate through which TV pictures — three every two minutes — are sent directly to Earth. Engineering measurements and all other scientific data are sent

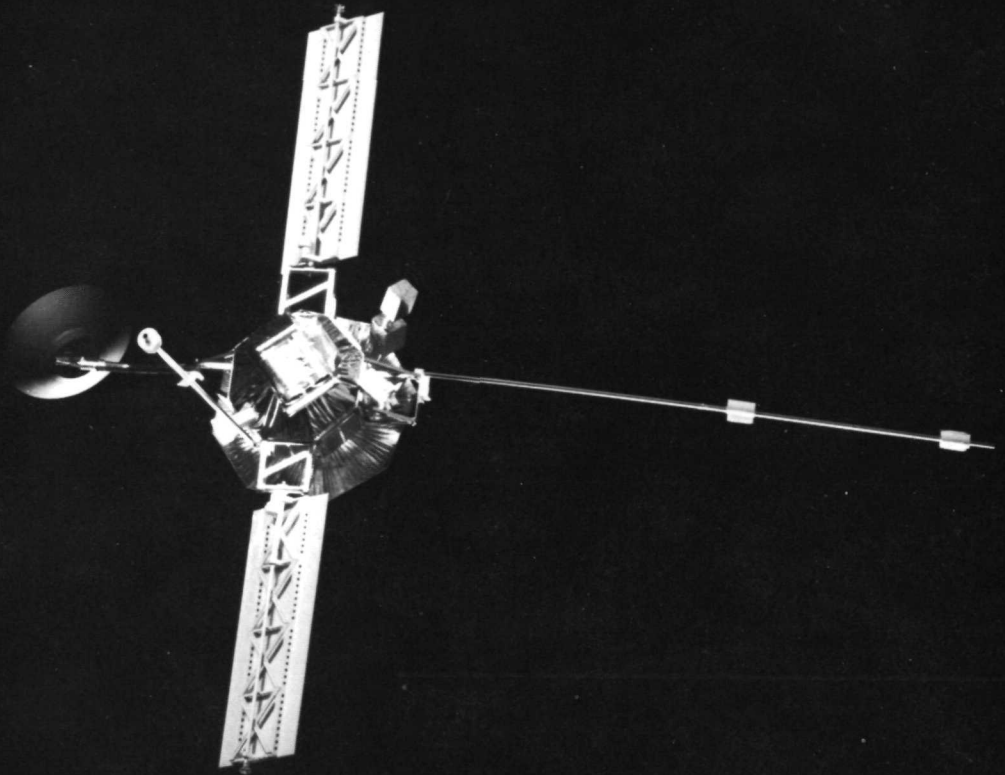
simultaneously at lower rates. This will continue for 22 hours, as UV scans and narrow-angle pictures with various filters rake the glowing clouds, with wide-angle images of large-scale clouds. Fields and particles investigations of the region inside the orbit of Venus will continue as well. Then the tape recorder will play out to Earth all the observations taken while Mariner was behind the planet, a day earlier. Close-up pictures, ultraviolet spectra, infrared temperatures, and the record of magnetic field fluctuations, charged-particle bombardment, and plasma flux will pour out into the hands of the waiting experimenters like a bushel of rubies.

Now the spacecraft has turned its path closer toward the Sun, slowing as it has plowed through a gravitational field almost as weighty as Earth's. It would have taken 40 times the impulse carried by the spacecraft propulsion system to equal the change which now will send the machine to Mercury. After the tape playback (twice to be sure), the data rate is reduced down to 22,050 bits per second, and Mariner is put to work recording batches of pictures for reduced-rate playback and transmission. In the meantime radio tracking carefully gauges the effect of the gravity turn at Venus. Four days after encounter, a trajectory correction maneuver takes the main errors out of the path to Mercury. Then for two weeks, at hourly intervals, Mariner's camera records pictures of Venus, charting the motion of the ultraviolet cloud features, until the planet is out of sight.

Artist's conception of Mariner Venus encounter (Sun at right)







## 5. DESTINATION MERCURY

From the last look at Venus to the first view of Mercury is four weeks as the Mariner flies, although from the closest approach at one planet to the next is a flight of over seven weeks. Like the comet, some two months earlier, the spacecraft speeds up as it drops in closer towards the Sun. A week into this second interplanetary cruise comes the last course-correction maneuver. It's the last chance to trim the trajectory for a perfect Mercury flyby, for after this point, for more than two months, Mariner will be too close to the Sun to turn out from behind its sunshade with absolute safety.

After this maneuver, the spacecraft computer's memory at last has room for the complex programming which will govern the 22-day automated survey of the planet Mercury from space. The week preceding, and two weeks following the day of closest approach, resemble the last two weeks of Mariner's retreat from Venus in that pictorial mosaics of the moderately distant planet will be recorded periodically on tape for playback to the scientists waiting on Earth; these operations are repetitive, and occupy relatively little attention in the computer instructions. It is the operations of the few hours and even few minutes which Mariner spends closest to Mercury which call for complicated instructions. The detailed pattern of what happens while the spacecraft is close to

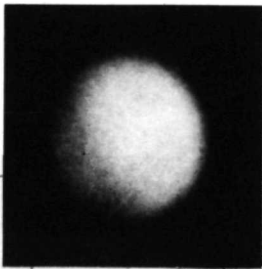
Mercury may be changed at the last minute on the basis of what appears in the daily picture surveys taken and sent back to Earth in the preceding week.

In the meantime, however, after Mariner has settled down on its final course to Mercury, the fields and particles experiments and dual-frequency radio investigation step into the foreground again. Since the spacecraft and its instruments came out through the plasma shock wave near Venus, they have been immersed in a purely solar sphere of influence. They are closer to the Sun than Venus, and by February 19, 1974, they pass the record of Mariner 5, achieved when that mission was shut down in November 1967. From here on the three related investigations are breaking new ground.

### Broiled World

Mercury is a very difficult planet to observe, not only because it is small and distant, but also — and very significantly — it is close to the Sun in our sky. Clouds do not block its surface from observation, like Venus, or even as much as Mars. But, like Venus, the closer Mercury is to Earth (the closest possible is over 50 million miles) the more of its surface is shrouded in

Below, Pic du Midi Observatory photo of Mercury, with A. Dollfus' map of the planet

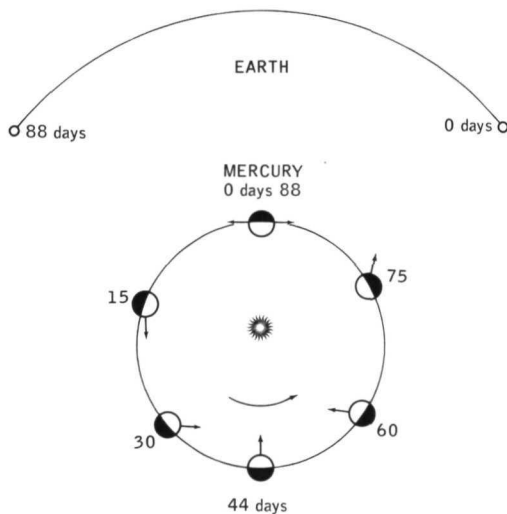


### MERCURY

Radius:	38% of Earth's
Mass:	6% of Earth's
"Year":	88 Earth days
Solar	
"Day":	176 Earth days
Sidereal	
Period:	59 Earth days
Distance	
from Sun:	40% of Earth's
Surface	
Gravity:	39% of Earth's
Atmospheric	
Pressure:	Negligible
Surface	
Temperature:	570° F (day), -260° F (night)

night. At the half-lit position, when the planet is relatively large, well-lit, and separated in angle from the Sun, Mercury is still only 18 to 25 degrees from the Sun – a twilight rather than an evening or morning star – and is almost as far away as the Sun. Like the Moon, it reflects only about 6% of the sunlight which falls on it.

Thus it is no wonder that our Earth-based maps of Mercury are so sketchy and indefinite. Another mark of the difficulty of learning much about Mercury is that until the mid-1960s there was little doubt in astronomers' minds that the planet kept the same face to the Sun, as the Moon does to Earth. It is now known, on the basis of planetary radar information, that Mercury rotates on its axis once in 58 days, while it goes around the Sun in 88 days. These motions are harmonious (2:3), and result in a solar day about 176 days long – that is, once every two of Mercury's years. Because the planet's orbit is



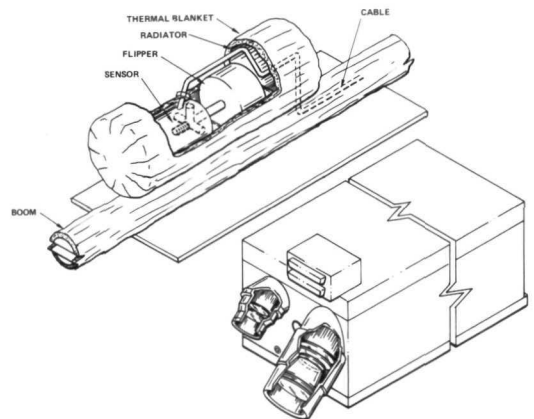
Mercury's revolution and rotation

eccentric, its speed around the orbit varies, so that the Sun seems to pursue a crooked path across the sky. From some longitudes there is a double dawn, in which the Sun rises, falls back, and rises again. Orbital eccentricity also means that the distance to the Sun varies considerably, in rhythm with the daily rotation. As a result, certain longitudes receive twice as much heat at noon as do others, and the peak temperatures vary accordingly.

Partly because its year is short, Mercury lines up directly between Sun and Earth, and appears to transit across the Sun's disk more often than Venus. It transited in 1960 and 1970, does so again November 11, 1973, while Mariner is still looking at the Earth.

Mercury may or may not have an atmosphere: the evidence is not definitive. The surface temperature varies from about 327°C at local noon to -123°C at local midnight. The surface gravity, 40% of Earth's, is greater than that of Mars, which has an atmosphere, but Mercury's smaller mass and the far higher temperature swing the odds against the inner planet's being able to hold much atmosphere.

The innermost planet receives the full blast of the Sun's radiation – from 4.7 to 10.5 times as much as Earth, depending on where Mercury is in its eccentric orbit. It also receives a correspondingly large share of the matter



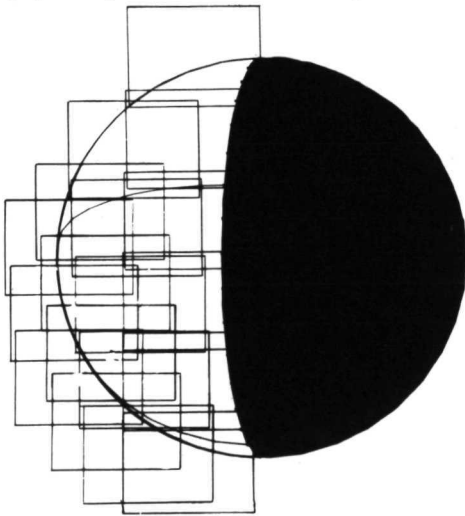
Magnetometer and charged-particle telescope

poured out from the Sun: the steady solar wind, the torrential solar-flare streams. It may be that Mercury catches a certain amount of this plasma and holds it as a transient atmosphere, like a pool in a river, before it runs on or seeps away into space. Mercury is certainly a plasma collector, and its surface could reveal clues regarding the history of the Sun, just as ancient sea bottoms chronicle, layer by layer, the biography of the Earth.

## First Flyby

Mariner will approach Mercury almost on a tangent to the planet's orbit near its furthest excursion from the Sun. Each day in the final week it will acquire and play back a set of 36 pictures (all the tape recorder will hold) in a full-color search for features of interest. Ultraviolet spectral scans will search for evidence of an atmosphere. In the next-to-last day, wide television sweeps will be made in the hope of spotting tiny satellites of Mercury, which is itself little larger than our Moon, and smaller than some outer-planet satellites.

The day of the close pass will begin with a series of picture surveys, giving color coverage at resolutions of 13 to 5 kilometers (8 to 3 miles). Five hours before closest approach, real-time picture transmittal begins. Because of the low data rate — higher than the "high" data rate of previous Mariners — the pictures are only partially scanned, so that only one-fourth



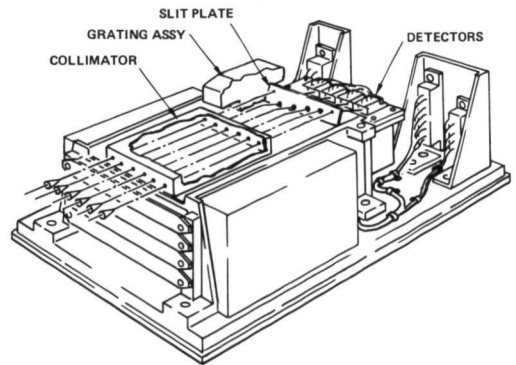
Mercury TV "mosaic"

the width is covered. However, if signal conditions permit, the high rate may be used at this time, permitting full-frame pictures. But the resolution improves, as the range shortens, to a best figure (to be achieved in recorded pictures) as good as 100 meters (330 feet).

The spacecraft will first fly into solar occultation — the shadow zone of Mercury. During this period, of course, the electrical equipment will be powered by the spacecraft

storage battery, and the spacecraft orientation will be maintained from gyro references in the absence of the Sun as a celestial lighthouse. The fields and particles experiments will observe a direct cross section of Mercury's plasma wake, a survey never before undertaken at another planet. The infrared radiometer will obtain a temperature profile 300 degrees around the planet from afternoon longitudes through the night side to a morning region. The occultation UV spectrometer will scan the limb or edge of the planetary disk as the Sun dips out of sight, and again as it emerges, for indications of an atmosphere. This mode of spectral analysis detects gas absorptions from solar ultraviolet, and can detect much smaller amounts of gas than the airglow instrument, which takes spectra before and after the night-side pass but, like the cameras, is blocked from viewing at this angle. TV operations will be suspended.

The scan platform will be swivelled to pick up Mercury as it reappears from behind



Mercury occultation UV spectrometer

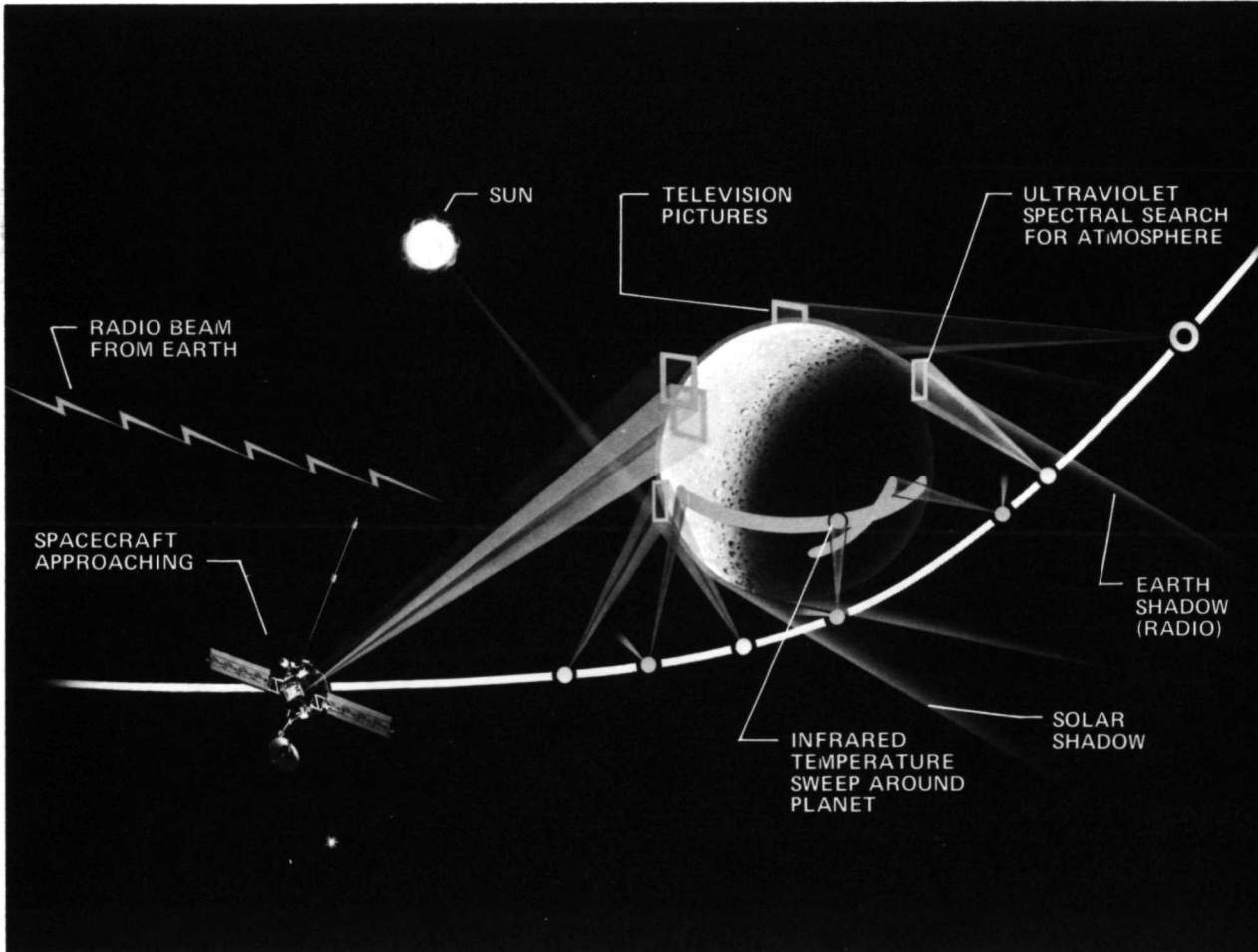
Mariner's sunshade. By this time, however, the spacecraft is in Earth occultation, and images are added to the other data being recorded for later playback. When the spacecraft passes into Mercury's radio shadow as seen from Earth, and again when it emerges some eleven minutes later, two-way dual-frequency radio transmissions using the standard S-band and experimental X-band radios will gather information on physical properties of Mercury's

atmosphere and dimensions of the solid planet.

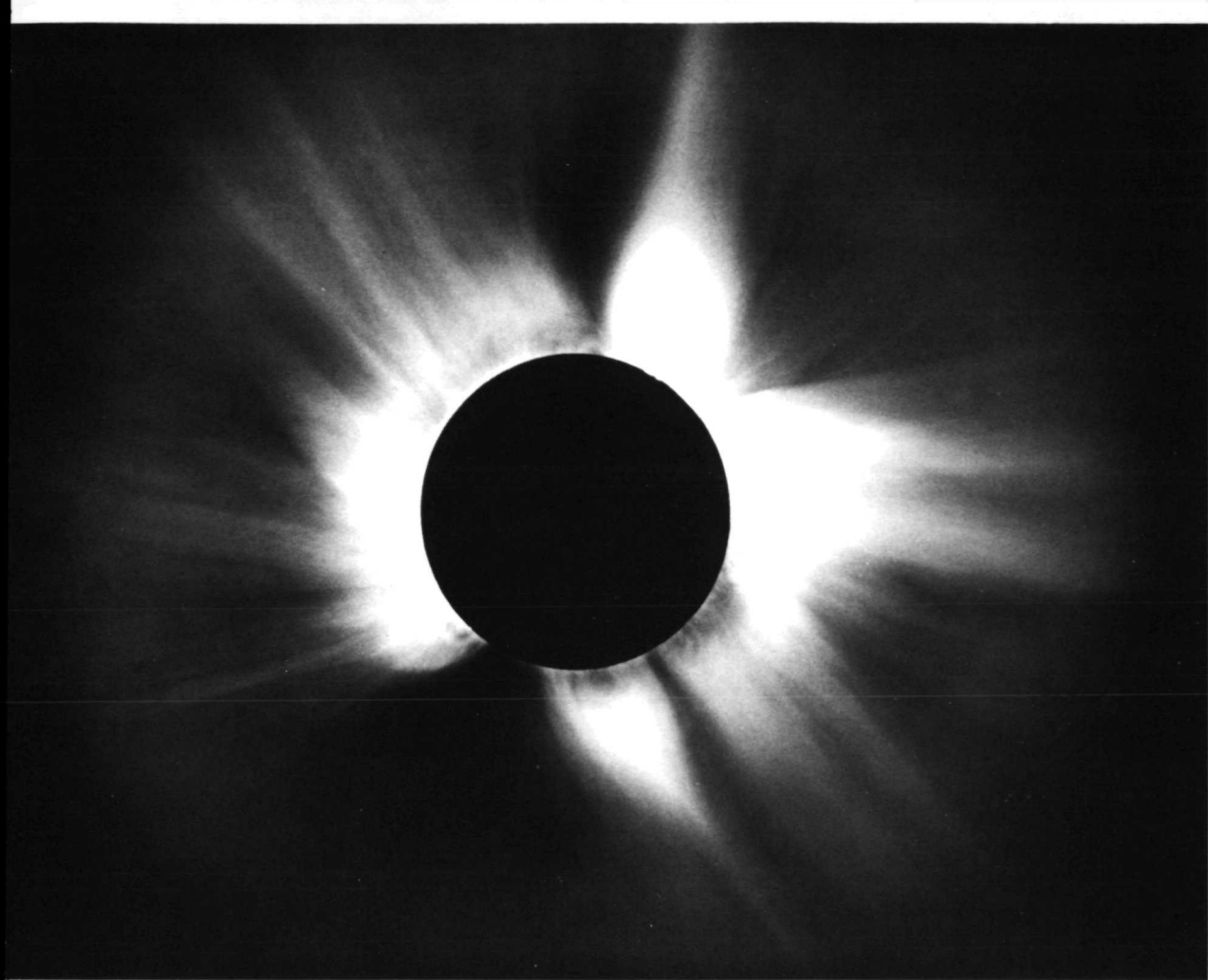
Once the Earth is in view again, real-time quarter-strip TV pictures will be transmitted. It should be remembered that all these changes of operating mode are controlled by the computer, acting on programming commands sent from Earth days before, and based on the best tracking information available. Thus the spacecraft responds when Earth is supposed to come in view, not when communications are actually restored. Real-time TV operations will continue for five hours. Then half of the close-up pictures recorded before and during the occultation will be played back.

With half the tape recorder's capacity now free, the spacecraft can begin recording sets of

18 full frames and playing them back, as was done during the approach. Then, 16 hours after the closest approach, the remainder of that period's recorded data come off the tape and back to the experimenters. For the next two weeks, a daily routine of recording and playing back a set of 36 pictures will carry Mercury, like Venus before it, virtually out of sight. Ultraviolet scans and the collecting of magnetic and plasma measurements will continue. Thirteen days after the flyby, 1000 km (621 miles) above the night side of Mercury, television operations will cease. The first Mercury encounter, and with it the formal two-planet Mariner mission of 1973-74, will be over.



Artist's conception of Mariner Mercury encounter (Earth at left)



## 6. RUNNING FREE

Just a few centuries ago, seafarers did a little of everything, fishing and fighting, map making and missionary work, science and survival. In the early days, space exploration had a similar multimedia quality to its scientific work: fields and particles, solar radiation, planetary close-ups, and the testing of spacecraft devices against the spaceflight environment – all of high interest, each confronting one or more instruments in a protean mission. Then came the age of specialization: the earlier mariner's ships became whalers, China Clippers, slavers, freighters, liners, tankers. Space exploration has specialized around the lunar landing, Earth

applications, the surface of Mars, the space environment of our planet. Yet a few purely scientific opportunities still call for the multiple investigation. Mariner Venus/Mercury 1973 is one of these.

Its first priority is the study of the planet Mercury, which has never before been investigated in this fashion. But the very nature of the mission brings the planet Venus and a new close view of the Sun before it, and flexibility in the equipment design plus the wide interests of the experimenters further broaden this Mariner's scientific view. It is an evolution, not a turning away, from the

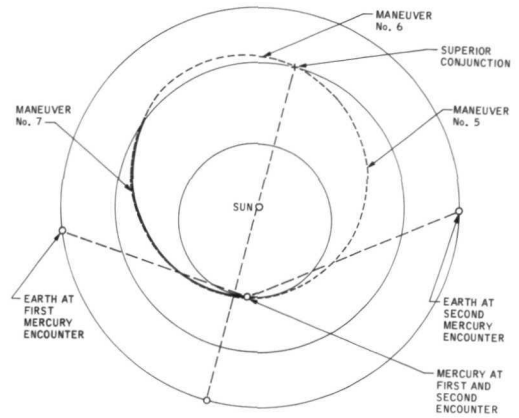
specialized efforts of the Mars Mariners. Most of its devices derive closely from earlier efforts: only the applications are new. And the ideas of adaptation and recombination are as old as science.

### Round Trip

In 1970, Giuseppe Colombo of the Instituto de Meccanica Applicata alle Macchine of Padua, Italy, suggested that Mariner's post-Mercury orbit might be very nearly synchronous with that of Mercury, and that a little adjustment might bring about a second encounter some six months — two Mercury years — after the first. This promising prospect, requiring accurate guidance through Mercury's gravitational field, and additional orbit-trimming maneuvers, proved to be within reach of the mission design.

The zone above Mercury through which the spacecraft must pass to be able to return to Mercury overlaps the target zone desired by Mariner experimenters. Accuracy requirements of the second gravity turn maneuver are no more stringent than for the first one, at Venus. And it is highly probable that enough fuel will be left after Mariner gets to Mercury for the three extra maneuvers before a return engagement. During the interval of 176 days, Earth would move around so that the interplanetary geometry is almost a mirror image of March 29. The spacecraft is expected to survive in orbit much longer than the eleven months from launch to the second Mercury pass. The scientific data return, in solar and planetary information, would be greatly increased.

The most important feature of the second Mercury encounter for the scientific experimenters would be the changed region of coverage. Where the first pass cuts through the solar plasma in the planet's wake, and views both the evening and morning regions of the surface in the equatorial zone, a second pass could either view one of the poles or fly by the sunlit part of the globe. A second factor — the passage of six months — will have less effect. It might be possible, with time, to detect some changes on surface features or in the atmosphere or plasma-sphere if the earlier pass



Mariner post-Mercury orbit

were repeated. It will be nearly the same time of "day" when Mariner returns to Mercury, but even slight changes in the longitude of the long-shadowed terminator will bring new surface features into high-contrast view. Whatever the geometry of the second pass, surface coverage would be expanded and improved.

This additional planetary flyby has not yet been formally authorized; it would entail more than doubling the planned duration of flight operations. It is enough, for awhile, to get Mariner to Mercury for the first time. Yet some scientists whisper: if a second flyby is feasible, what about a third, or more?

### Relativity

One final scientific quest in which Mariner Venus/Mercury 1973 is involved is more broad and fundamental than any of those for which instruments are installed on the spacecraft. It has to do with the fabric of space itself, and uses the whole Mariner mission as its sensing probe.

A spacecraft's motion is mostly determined by gravitation. Planets and other visible bodies are tracked optically, mostly through the measurement of angles, but a spacecraft's position and motion are derived from ranging and doppler measurements using a coherent two-way radio signal. These measurements are very precise; in 1969 they led to the discovery of mass concentrations buried in the Moon, beneath some of the lunar seas. Scientists hope

to use Mariner for similar studies of Mercury. Throughout the lunar and planetary program such precise tracking has refined our knowledge of the positions, motions, and masses of various planets in relation to each other and the Sun. Essentially this has been a dynamic mapping of the solar and planetary gravitational fields.

In 1915 Albert Einstein "generalized" his theory of relativity – of the relations between space and time – to include gravity. He described this property of matter in terms of a distortion, or stretching, of space radially about every mass. In this view, if space were two-dimensional, it would be flat in the absence of gravitation but stretched down like a trumpet's mouth around, for instance, the Sun.

General relativity could be tested to some degree from its predictions. Mercury's orbit, partly in the horn, should behave in a particular way; starlight coming close by the Sun – and visible during an eclipse – should be bent toward it; radio waves traversing the distorted space should run a longer path than the corresponding straight line. These predictions have all been tested, the radio-ranging experiment in a previous Mariner mission. In the 1974 Mercury encounters, Mariner can help refine the Mercury orbital test by measuring the Mercury-Earth distance to an accuracy of 15 meters (50 feet); when it passes the opposite

side of the Sun from Earth its dual radio signal can retrace the earlier Mariner test.

### **Souvenirs**

Interplanetary and deep-space travel are so difficult and expensive in energy that only the most precious commodities can be brought back. Certainly the most precious thing Earth's civilization can import is information. Science, the space program, and Mariner Venus/Mercury 1973 share this objective.

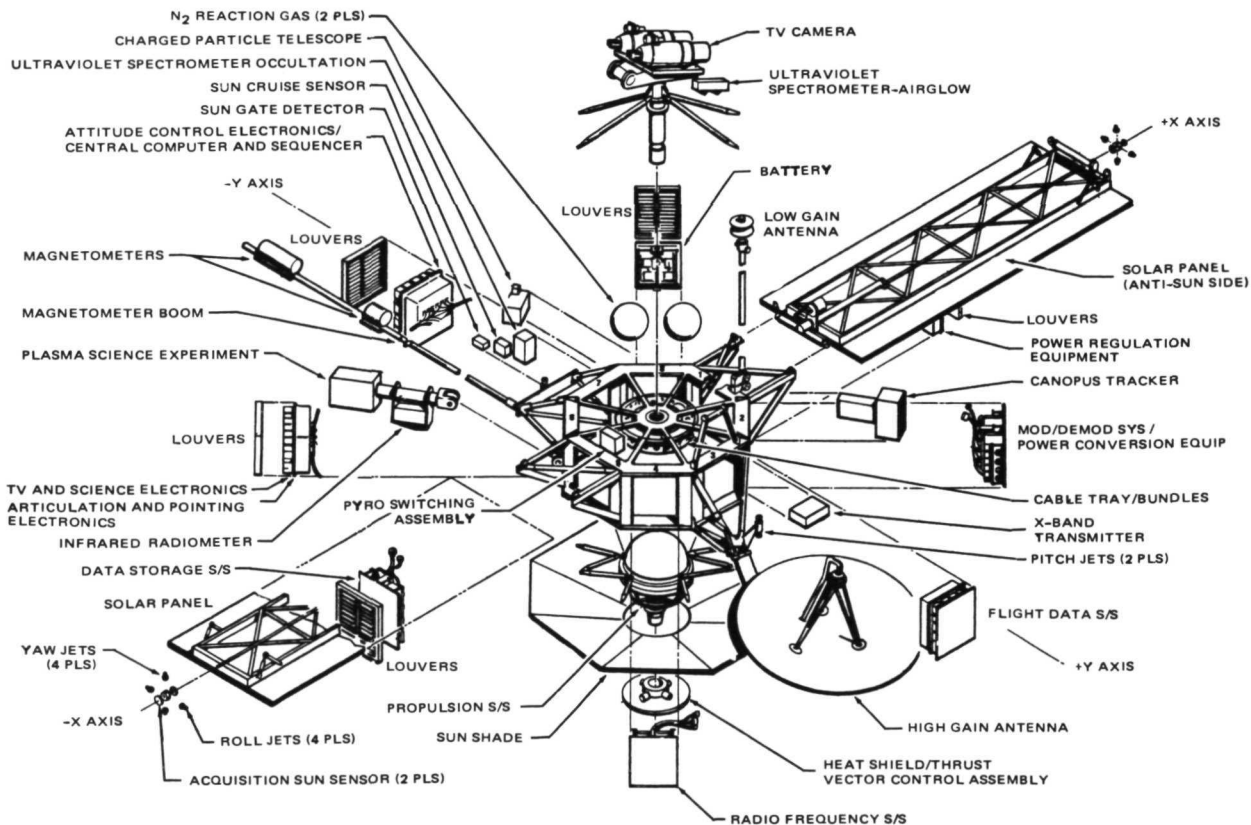
The mission will have done its immediate job when the information it gathers about Venus, Mercury, the Sun, and the space enclosing them has been returned over the deep space communications link. But for the scientists, that is only the beginning. Interpreting the measurements, and building them into an understandable world picture, is a continuing and ever-growing endeavor. As the Mariner inquiries about Venus and Mercury have been based on previous observations and concepts, so new questions will rise from the results of this flight.

The study of our world's environment in the solar system and the study of different planets in comparison to our own are two important ways of learning about the Earth we inhabit. Mariner Venus/Mercury 1973 is designed to add a new world's worth of information to this learning.



Small Worlds in the Solar System	Mercury	Venus	Earth	Moon	Mars
Radius: kilometers miles	2420 1500	6050 3760	6370 3960	1740 1080	3390 2100
Distance from Sun: million km million miles	59 37	108 67	150 93	150± 93±	228 142
Orbital period, Earth days	88	225	365¼	29	687
Solar day, Earth days	176	127*	1	29	1
Atmosphere	little if any	thick, opaque	clear/cloudy	none	thin
Surface pressure, Earth = 1	-----	~ 90	1.00	0	0.07
Composition	-----	95% CO <sub>2</sub> , N <sub>2</sub> , etc.	79% N <sub>2</sub> , 19% O <sub>2</sub>	----	CO <sub>2</sub>
Clouds	-----	reflecting, 75 km high, all over	H <sub>2</sub> O, variable	----	dust, stormy; also CO <sub>2</sub> frost
Nature of Surface	unknown	Craters, unknown	75% water, differentiated land	Craters, maria	Craters, differentiated land
Surface temperature, ° F	-260 to +560	~ 800	-30 to +115	-245 to +270	-190 to +65
Surface gravity (Earth = 1)	39%	91%	1	17%	38%

\* Cloud-deck rotation period: about four Earth days.



Exploded view, Mariner Venus/Mercury spacecraft