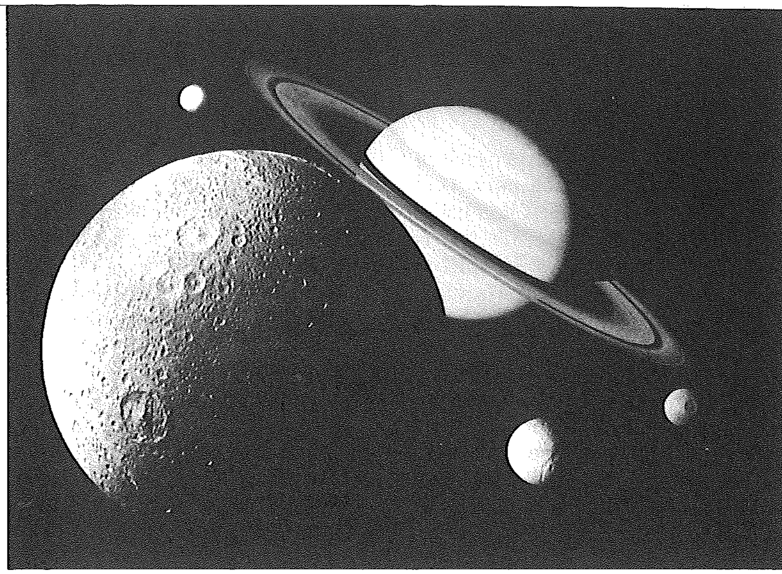

# Planetary Exploration

By Clark R. Chapman

*Institute Scientist and member of the MESSENGER Science Team*
*Southwest Research Institute, Boulder, Colorado*

A salient feature of our species is the impetus to explore. Now that our own planet is well explored, the Space Age has opened the heavens for our excursions. Bearing ever more sophisticated computers and instruments, robotic spacecraft have ventured to planets, moons, asteroids, and comets throughout the Sun's immense realm.The first interplanetary craft was Mariner 2, which reconnoitered Venus in 1962, confirming indications from Earth-based radio astronomical data that its surface is extremely hot—much too hot for the Venusian creatures imagined by mid-twentieth-century science fiction writers.

If you don't remember, or haven't heard of Mariner 2's historic flight, it's probably because it lacked a camera. It is difficult to travel vicariously to distant worlds if you can't see them. The next successful planetary spacecraft, Mariner 4, carried a camera to the red planet, Mars. Despite a light leak in the simple device, which partly washed out the images, the message from the returned pictures of Moon-like craters was startling. Despite widespread hopes (or fears) that Mars was an abode for life, the *New York Times'* lead editorial on July 30, 1965, said it all: "The Dead Planet." Nearly every subsequent deep space mission has carried a camera, so that we might see our discoveries as well as measure them with the other wondrous instruments that have been engineered for spacecraft missions.

Nearly every time we see a new place in the solar system, or see it in a new way (closer up, or in a different color or wavelength of electromagnetic radiation), we are surprised. With rare exceptions, theorists are unable to predict what might be found and it is raw, unexpected data that drive our understanding of our neighborhood in the universe. Such was the case for Mars. Later Mariner spacecraft revealed dramatic volcanoes, enormous canyons, and — most surprisingly — dry river valleys distributed all across the Martian surface. Mariner 4 had just happened to snap pictures of a Moon-like part of the planet, but most of Mars is very different from the Moon, and our hopes for Martian life revived. More recently, Mars has again tickled our fancies with microscopic worm-like shapes (which look like bacterial life but probably aren't) and with close-ups of modern-day gullies, dripping water from beneath Martian rock ledges. Mars may or may not be a planet where life once thrived and may still be hanging on in subterranean oases.

Spacecraft have also ventured immense distances to explore Saturn, Jupiter, Uranus, Neptune and their many moons and rings. Others have returned to Venus and Mars. Many marvelous things have been found, from the sulfurous volcanoes on Jupiter's moon Io to the fountaining geysers on Neptune's frigid moon Triton. Giant ephemeral storms come and go in Neptune's dimly lit atmosphere and comets crash into Jupiter. Still other robotic spacecraft have visited asteroids and comets. Last year, one even made an unplanned landing on the surface of the Earth-approaching asteroid, Eros.

## An Enigmatic, Elusive Planet

Forty years after Mariner 2, planetary exploration has only just begun, and — right now, in 2002 — many more missions are on drawing boards, nearing the launch pad, or even en route across interplanetary space to their targets. I want to tell you more about one of the most challenging missions that will be conducted this decade: sending the MESSENGER spacecraft to orbit the planet Mercury. ("MESSENGER", besides recalling that the Roman god Mercury was the messenger of Zeus, is an acronym for the "MErcury: Surface, Space ENvironment, GEochemistry, Ranging" mission).

Mercury is a diminutive planet, smaller than outer planet moons Ganymede and Titan, yet, it may be the linch-pin to understanding planetary systems. Although Mercury is usually closer to Earth than Mars, it has withheld its secrets for far too long. The innermost planet, it plays tag with the Sun and can rarely be seen, setting soon after sunset or rising shortly before the Sun. At best, it is very low above the horizon during dusk or twilight. Our largest, finest telescopes — like Hubble — cannot look toward Mercury, for fear that stray sunlight might damage the equipment. For many years, we didn't even know how rapidly Mercury spins on its axis. It was long thought that it always kept the same face to the Sun, like the Moon does to the Earth, so that Mercury's day was the same as its year — 88 Earth days.

Persevering astronomers gradually gleaned a few facts about Mercury. First, its day is exactly two-thirds as long as its year. At least that's how fast it spins. But its orbital motion around the Sun is so fast, slowing the Sun's apparent westward motion in Mercury's sky (sometimes it even reverses, moving east, before heading west again), that it takes two Mercurian years — or three Mercurian days — between sunrise and the next sunrise (a "solar day"). Another vital trait of Mercury is its bulk density: for such a small body, Mercury is relatively massive (it "weighs" a lot). Just as a steel ball feels heavier than a rubber ball the same size, Mercury's mass is a clue that it is made of some dense materials. Indeed, only iron is both dense enough and abundant enough in the cosmos to account for Mercury's density. Why should Mercury contain a higher proportion of iron than any other planet? It is a question that needs to be answered.

Astronomers struggled, with their telescopes, to glimpse features on Mercury's small, blurry image as the planet settled behind distant tree tops...but it yielded few of its secrets until 1974 when the last of the Mariner spacecraft was sent first past Venus and then sunwards to fly past Mercury. By an ingenious trick of celestial pinball wizardry, the spacecraft made two more passes by the sun-drenched planet during the ensuing year.

Several stunning surprises were returned in Mariner 10's data stream. First, the planet has a magnetic field, rather like the Earth's although smaller and weaker...despite researchers' confident expectation that Mercury would possess no magnetic field at all. Second, the planet's cratered surface sports hundreds of superimposed escarpments — curving cliffs, typically hundreds of meters high and tens to hundreds of kilometers long. Mercury's crust resembles the wrinkled skin of an old, dried-out, shrunken apple. And that is a fair analogy for the geophysical interpretation, namely that the once-hot interior of Mercury long ago had cooled and shrunken, wrinkling its brittle, rocky crust. The irony is that these two remarkable discoveries about Mercury seem to be self-contradictory. An active magnetic field must arise from the churning motions within a still-active, molten core (or so theorists believe)...hardly compatible with the escarpments' evidence that Mercury's interior had long ago cooled, shrunk, and died.

More surprises about Mercury were learned in the 1980s and 1990s from use of upgraded instrumentation on Earth. I'll mention just one. About a decade ago, radar echoes from

Mercury revealed stunning evidence that this Sun-broiled planet has ice at its poles! The ice doesn't form immense ice caps, as on Earth and Mars. Instead, it appears that water molecules have been trapped and frozen within the soils of deep, permanently shadowed impact craters near Mercury's north and south poles...perhaps the remnants of comets that crashed into the planet.

As with all discoveries, scientists bicker about the interpretations. Some argue that the polar deposits aren't water ice at all, but rather sulfur. It will be a challenge to figure out what the deposits are, because they will be totally invisible to many of MESSENGER's instruments. The very condition that preserves the ice deposits so close to the solar inferno — hiding in shadows — means that they are never illuminated by the Sun, so we can't ever see them. Perhaps other instruments will be able to "sniff" them, however, and MESSENGER scientists are determined to solve the mystery of what the deposits are and why they are there. (There are no equivalent deposits on the Moon, despite its having a somewhat more hospitable environment.) There are no end to mysteries about Mercury, but one raised a few years ago may have gone away: preliminary radar echoes from the side of Mercury *not* seen during any of Mariner 10's three fly-bys seemed to suggest that an enormous volcano — unlike anything seen on the 45% of Mercury that was photographed — might be awaiting MESSENGER's scrutiny. But very recent higher resolution data, enabled by technical upgrades to the world's largest dish, nestled among Puerto Rican hills, show that the feature is just one more large impact crater.

Perhaps the most surprising attribute of Mercury has been appreciated only in the last few years, as astronomers finally found a plethora of planets around other stars. It once seemed natural that the solar system's innermost planet would be small and iron-rich, lacking those materials that can exist only in colder parts of the system, farther from the Sun. And equally natural that the outer planets, Jupiter, Saturn, Uranus, and Neptune, would be the giant planets, collecting all the ices and gasses that couldn't exist near the Sun. But most planetary systems that have been discovered around other stars have "Jupiters" in close, where the mini-planet Mercury orbits our own star. Mercury, and indeed our entire planetary system, now seems *odd* compared with most planetary systems. Maybe our concocted theories that make our own neighbor planets seem almost foreordained are wanting and *we* are actually the peculiar ones. Or maybe our perceptions of other planetary systems are premature — after all, our current techniques can detect only "Jupiters", not "Mercurys." Learning more about our own Mercury may be an easier approach to understanding how planets form than by trying to decipher the immensely distant planetary systems around other stars.

## A MESSENGER to Mercury

In the late 1970's, after Mariner 10's historic reconnaissance of Mercury, planetary researchers were eager to return to Mercury...to stay longer and to take instruments that would be more revealing of the planet's nature. Mariner 10, for example, bore no instrument sensitive to the planet's chemical or mineralogical composition. But scientists' well-whetted appetites for more Mercury data weren't sufficient to make a new mission happen. The obstacles were technological. First, somewhat paradoxically, it is very difficult to get to Mercury, especially if you want to stay...and most cutting-edge science goals demanded that a spacecraft go into orbit around Mercury, not merely zoom past. A spacecraft, like Mariner 10, can't just be "dropped" toward the Sun. It took a lot of rocket thrust to get Mariner 10 into a trajectory that reached down to Mercury's orbit. In order, additionally, to match Mercury's motion along its orbit and stay, even more "delta-V" is necessary...more than any available rocket could provide.

The second inhibition to an intensive Mercury mission is more obvious: How do we keep a spacecraft from melting and burning up near Mercury? Not only must it survive the excruciating temperatures of more than ten Suns, but the instruments are trying to look down on a surface that can reach 700K, about twice the temperature (above absolute zero) of boiling water. Unable to cool off between the omnipresent inferno behind and the almost glowing planet below, it would take an engineering miracle to preserve a spacecraft safely in orbit around Mercury.

So spacecraft were sent, instead, toward Venus, Mars, Jupiter, Saturn, comets, and asteroids. But Mercury's challenges were eventually engaged by resourceful engineers. First, Chen-wan Yen, a Jet Propulsion Laboratory specialist in spacecraft trajectories, made a stunning discovery in the early 1980s. By flying past Venus — and Mercury itself — multiple times, those planet's gravitational tugs could dramatically augment any rocket's capabilities, and guide a spacecraft into orbit around the innermost planet. Her insight may be the single most important development that enabled MESSENGER.

Once engineers knew that a spacecraft could be dropped into orbit around Mercury, they set about seriously trying to understand how to protect a spacecraft from the excruciating heat in order to preserve vital spacecraft and instrumental capabilities while immersed in a virtual blast furnace. A critical component is a ceramic-cloth sunshield; no active coolant need be carried on board. On paper, it finally seemed that a mission could be attempted. A team of scientists and engineers, led by Carnegie Institution geophysicist Sean Solomon, proposed the MESSENGER Mercury mission to NASA as part of the new "Discovery" series of entrepreneurial missions of exploration. It took two attempts in the competitive proposal arena before MESSENGER was selected, in July 1999, for development.

Engineers at Johns Hopkins University's Applied Physics Laboratory, in Laurel, Maryland, set about drawing up plans and prototypes to turn the engineering concepts — with the help of several contractors from around the country — into viable hardware that might realize the scientists' dreams. It wasn't easy. Early samples of the solar panels, which would convert the all-too-brilliant sunlight into electrical energy to power the spacecraft's instruments, computers and communication systems, first failed some of their environmental tests. (The cutting edge nature of the technology can be appreciated, but not comprehended, when I tell you that the panels involve placing a cerium-oxide-doped borosilicate glass over gallium-arsenide cells.) Later on, designs to protect the sensitive spacecraft instruments from the brutal environment required the addition of more shielding, raising the spacecraft's mass toward the limit that the Delta II rocket could launch.

We human beings are very protected by our life-sustaining ecosystem on Earth. It takes extraordinary life-support systems to send an astronaut — safely — only as far as the Moon. Mercury's hostile environment is challenging for almost anything we can manufacture on Earth. Yet, driven by our need to know, MESSENGER's engineers finally designed equipment that can withstand — so skeptical reviewers have finally affirmed — the worst the Sun and Mercury can throw at the MESSENGER spacecraft.

All of the instruments now have prototypes working in laboratories across the nation. And, less than a year from now, engineers will be integrating the final, space-qualified instruments into the spacecraft, which will eventually weigh nearly 500 kilograms. Special, so-called phased-array antennas (which look nothing like the dishes used by most previous spacecraft) will eventually send the data back to Earth. But first, after expenditure of most of the several hundred million dollars of funds, MESSENGER must survive its shipment to Florida at the end of next year and, especially, its time-critical launch in April 2004.

MESSENGER will first fly by Venus, twice according to Chen-wan Yen's prescription, before it eventually reaches Mercury. The two Venus fly-bys (in June 2004 and March 2006) will enable scientists to test the instruments before their crucial operations at Mercury...and we may learn a little bit more about our closest planetary neighbor, Venus, as a bonus. Finally, in mid-2007 and again nine months later, MESSENGER will zip past Mercury, just 200 km above its surface, taking advantage of the dense planet's gravity to shape its path in anticipation of the final orbit-insertion maneuver that will put MESSENGER into orbit — albeit a very elongated one — in early 2009. For the next year, the full power of MESSENGER's instruments will be dedicated to resolving the puzzling aspects of the planet with an iron heart.

For a focussed, relatively low-cost mission, MESSENGER is loaded with diverse instruments, all designed to work in the extreme environment of Mercury. Of course, the spacecraft will carry a camera system, with both wide-angle and telescopic capabilities, looking at the cratered planet (in wide-angle mode) through twelve different color filters. Another instrument, being built in Boulder, Colorado, will sacrifice some spatial resolution to focus on Mercury's spectral traits, at wavelengths ranging from the ultraviolet, through the visible, to the near-infrared; it will assess the planet's tenuous (close to vacuum) atmosphere and the mineralogy of the planet's surface. Gamma-ray and X-ray detectors will probe the chemical/mineralogical composition of Mercury's surface. Still other instruments will probe the planet's magnetic field and charged-particle environment. One of the most important challenges will be addressed by a laser, which can measure the distance to the planet with extreme precision — to half a meter, or so. The laser altimeter's most significant task is to detect minor motions of Mercury that should reveal the existence and extent of any liquid core that Mercury might possess.

The entire MESSENGER project is a great gamble, worthy of past intrepid explorers. This mission must first weather the trials and tribulations of launch, the possibilities of technical failures that have marred some recent Mars missions, and survival for nearly a decade in one of the most difficult environments in the solar system. It also faces the omnipresent danger of bureaucratic and political vagaries that prematurely cancelled at least one earlier planetary mission that had already reached MESSENGER's current level of readiness. A decade from now, I hope and expect that scientists — including myself — will be poring over an incredible dataset about this remarkable world, and asking new questions that we never could have asked before. That is the nature of exploration: there is always more explore.