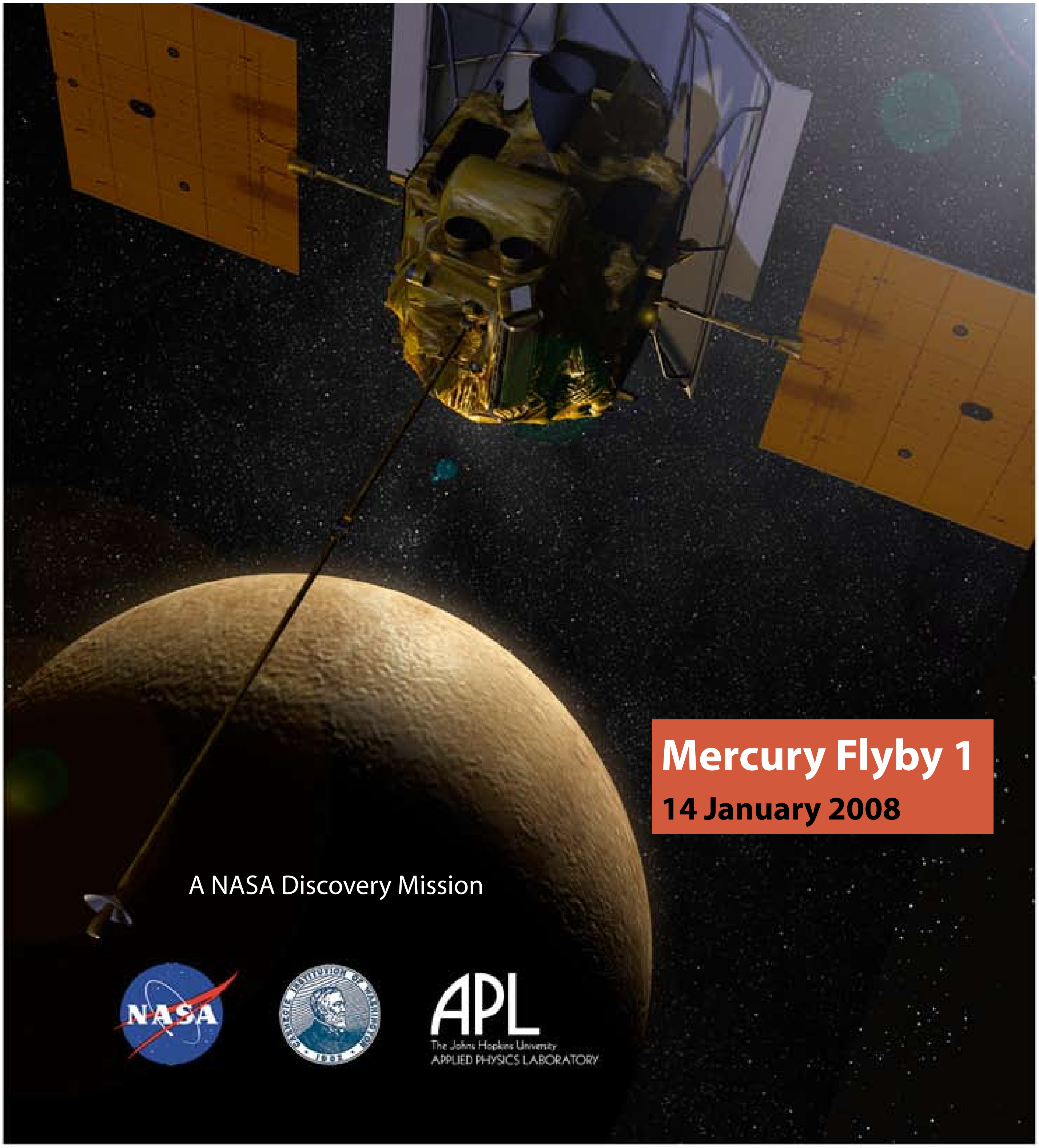
MESSENGER

MErcury Surface, Space ENvironment, GEochemistry, and Ranging



Mercury Flyby 1

14 January 2008

A NASA Discovery Mission

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The information in this press kit was current as of January 10, 2008.
For mission updates, visit http://messenger.jhuapl.edu/.

General Release: MESSENGER Set for Historic Mercury Flyby

NASA will return to Mercury for the first time in almost 33 years on January 14, 2008, when the MESSENGER spacecraft makes its first flyby of the Sun's closest neighbor, capturing images of large portions of the planet never before seen. The probe will make its closest approach to Mercury at 2:04 p.m. EST that day, skimming 200 kilometers (124 miles) above its surface. This encounter will provide a critical gravity assist needed to keep the spacecraft on track for its 2011 orbit insertion around Mercury.

"The MESSENGER Science Team is extremely excited about this flyby," says Dr. Sean C. Solomon, MESSENGER principal investigator, from the Carnegie Institution of Washington." We are about to enjoy our first close-up view of Mercury in more than three decades, and a successful gravity assist will ensure that MESSENGER remains on the trajectory needed to place it into orbit around the innermost planet for the first time."

During the flyby, the probe's instruments will make the first up-close measurements of the planet since Mariner 10's third and final flyby of Mercury on March 16, 1975, and will gather data essential to planning the MESSENGER mission's orbital phase. MESSENGER's seven scientific instruments will begin to address the mission goals of:

- mapping the elemental and mineralogical composition of Mercury's surface;
- imaging globally the surface at a resolution of hundreds of meters or better;
- determining the structure of the planet's magnetic field;
- measuring the planet's gravitational field structure; and
- characterizing exospheric neutral particles and magnetospheric ions and electrons.

A Close-up of Mercury

The cameras onboard MESSENGER will take more than 1,200 images of Mercury from approach through encounter and departure. "When the Mariner 10 spacecraft did its flybys in the mid-1970s, it saw only one hemisphere – a little less than half the planet," notes Dr. Louise M. Prockter, instrument scientist for the Mercury Dual Imaging System, and a scientist at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Md. "During this flyby we will begin to image the hemisphere that has never been seen by a spacecraft and at resolutions that are comparable to or better than those acquired by Mariner 10 and in a number of different color filters so that we can start to get an idea of the composition of the surface."

One site of great interest is the Caloris basin, an impact feature about 1,300 kilometers (808 miles) in diameter and one of the largest impact basins in the solar system. "Caloris is huge, about a quarter of the diameter of Mercury, with rings of mountains within it that are up to three kilometers high," says Prockter."Mariner 10 saw a little less than half of it. During this first flyby, we will image the other side of Caloris. These impact basins act like giant natural drills, pulling up material from underneath the surface and spreading it out around the crater. By looking through different color filters we can start to understand what the composition of the Caloris basin may be and learn something about the subsurface of Mercury."

MESSENGER instruments will provide the first spacecraft measurements of the mineralogical and chemical composition of Mercury's surface. The visible-near infrared and ultraviolet-visible spectrometers will measure surface reflectance spectra that will reveal important mineral species. Gamma-ray, X-ray, and neutron spectrometer measurements will provide insight into elemental composition.

During the flyby, Doppler measurements will provide the first glimpse of Mercury's gravity field structure since Mariner 10. The long-wavelength components of the gravity field will yield key information on the planet's internal structure, particularly the size of Mercury's core.

The encounter provides an opportunity to examine Mercury's environment in ways not possible from orbit because of operational constraints. The flyby will yield low-altitude measurements of Mercury's magnetic field near the planet's equator. These observations will complement measurements that will be obtained during the later orbital phase.

The flyby is an opportunity to get a jump start on mapping the exosphere with ultraviolet observations and documenting the energetic particle and plasma population of Mercury's magnetosphere. In addition, the flyby trajectory enables measurements of the particle and plasma characteristics of Mercury's magnetotail, which will not be possible from Mercury orbit.

MESSENGER is slightly more than halfway through a 4.9-billion mile (7.9-billion kilometer) journey to Mercury orbit that includes more than 15 trips around the Sun. It has already flown past Earth once (August 2, 2005) and Venus twice (October 24, 2006, and June 5, 2007). Three passes of Mercury, in January 2008, October 2008, and September 2009, will use the pull of the planet's gravity to guide MESSENGER progressively closer to Mercury's orbit, so that orbit insertion can be accomplished at the fourth Mercury encounter in March 2011.

"The complexity of this mission, with its numerous flybys and multitude of maneuvers, requires close and constant attention," says MESSENGER project manager Peter D. Bedini, of APL. "MESSENGER is being driven by a team of extremely talented and dedicated engineers and scientists who are fully engaged and excited by the discoveries before them."

The MESSENGER project is the seventh in NASA's Discovery Program of low-cost, scientifically focused space missions. Solomon leads the mission as principal investigator; APL manages the mission for NASA's Science Mission Directorate and designed, built, and operates the MESSENGER spacecraft. MESSENGER's science instruments were built by APL; NASA Goddard Space Flight Center, Greenbelt, Md.; University of Michigan, Ann Arbor; and the Laboratory for Atmospheric and Space Physics at the University of Colorado, Boulder; with the support of subcontractors across the United States and Europe. GenCorp Aerojet, Sacramento, Calif., and Composite Optics Inc., San Diego, Calif., respectively, provided MESSENGER's propulsion system and composite structure.

The MESSENGER Science Team, recently augmented by an impressive array of experts participating in NASA's MESSENGER Participating Scientist Program, includes 46 scientists from 26 institutions. A complete list can be found at http://messenger.jhuapl.edu/who_we_are/science_team.html. Additional information about MESSENGER is available on the Web at: http://messenger.jhuapl.edu.

Media Services Information

News and Status Reports

NASA and the MESSENGER team will issue periodic news releases and status reports on mission activities and make them available online at http://messenger.jhuapl.edu and www.nasa.gov.

When events and science results merit, the team will hold media briefings at NASA Headquarters in Washington or the Johns Hopkins University Applied Physics Laboratory in Laurel, Md. Briefings will be carried on NASA TV and the NASA Web site.

NASA Television

NASA Television is carried on the Web and on an MPEG-2 digital signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. It is available in Alaska and Hawaii on AMC-7, at 137 degrees west longitude, transponder 18C, at 4060 MHz, horizontal polarization. A Digital Video Broadcast-compliant Integrated Receiver Decoder is required for reception. For NASA TV information and schedules on the Web, visit www.nasa.gov/ntv.

MESSENGER on the Web

MESSENGER information – including an electronic copy of this press kit, press releases, fact sheets, mission details and background, status reports, and images – is available on the Web at http://messenger.jhuapl.edu. MESSENGER multimedia files, background information, and news are also available at www.nasa.gov/messenger.

December 19, 2007
MESSENGER ZEROS IN ON MERCURY

MESSENGER's nineteenth trajectory-correction maneuver (TCM-19) completed on December 19 lasted 110 seconds and adjusted the spacecraft's velocity by 1.1 meters per second (3.6 feet per second). [more]

Instrument Scientist Louise Prockter discusses the importance of the observations the Mercury Dual Imaging System (MDIS) will make at Mercury.

Quick Facts

Spacecraft

Size: Main spacecraft body is 1.42 meters (56 inches) tall, 1.85 meters (73 inches) wide, and 1.27 meters (50 inches) deep; a front-mounted ceramic-fabric sunshade is 2.5 meters tall and 2 meters across (8 feet by 6 feet); two rotatable solar panel "wings" extend about six meters (20 feet) from end to end across the spacecraft.

Launch weight: Approximately 1,107 kilograms (2,441 pounds); included 599.4 kilograms (1,321 pounds) of propellant and 507.9 kilograms (1,120 pounds) "dry" spacecraft and instruments.

Power: Two body-mounted gallium arsenide solar panels; nickel-hydrogen battery. The solar-panel power system provided about 390 watts near Earth and will provide 640 watts in Mercury orbit.

Propulsion: Dual-mode system with one bipropellant (hydrazine and nitrogen tetroxide) thruster for large maneuvers; 16 hydrazine monopropellant thrusters for small trajectory adjustments and attitude control.

Science instruments: Wide- and narrow-angle color and monochrome imager; gamma-ray and neutron spectrometer; X-ray spectrometer; energetic particle and plasma spectrometer; atmospheric and surface composition spectrometer; laser altimeter; magnetometer; radio science experiment.

Mission

Launch: August 3, 2004, from Launch Pad 17B at Cape Canaveral Air Force Station, Fla., at 2:15:56 a.m. EDT aboard a three-stage Boeing Delta II rocket (Delta II 7925-H).

Gravity assist flybys: Earth (1) August 2005; Venus (2) October 2006, June 2007; Mercury (3) January 2008, October 2008, September 2009.

Enter Mercury orbit: March 2011.

Total distance traveled from Earth to Mercury orbit: 7.9 billion kilometers (4.9 billion miles). Spacecraft circles the Sun 15 times from launch to Mercury orbit.

Primary mission at Mercury: Orbit for one Earth year (equivalent to just over four Mercury years, or two Mercury solar days), collecting data on the composition and structure of Mercury's crust, its topography and geologic history, the nature of its thin atmosphere and active magnetosphere, and the makeup of its core and polar materials.

Program

Cost: approximately $446 million (including spacecraft and instrument development, launch vehicle, mission operations and data analysis). This is just under $1.50 for each current U.S. resident.

For comparison, Mariner 10 cost $135M in 1975 dollars, including all three flybys and the launch vehicle. Add "indirect" costs and account for inflation, and the mission would cost about $448 M today.

Mercury at a Glance

General

- One of five planets known to ancient astronomers, in Roman mythology Mercury was the fleet-footed messenger of the gods, a fitting name for a planet that moves quickly across the sky.
- The closest planet to the Sun, Mercury is now also the smallest planet in the solar system.
- Mercury has been visited by only one spacecraft; NASA's Mariner 10 examined less than half the surface in detail in 1974 and 1975.

Physical Characteristics

- Mercury's diameter is 4,880 kilometers (3,032 miles), about one-third the size of Earth and only slightly larger than our Moon.
- The densest planet in the solar system (when corrected for compression), its density is 5.3 times greater than that of water.
- The largest known feature on Mercury's pockmarked surface is the Caloris basin (1,300 kilometers or 810 miles in diameter), likely created by an ancient asteroid impact.
- Mercury's surface is a combination of craters, smooth plains, and long, winding cliffs.
- There possibly is water ice on the permanently shadowed crater floors in the polar regions.
- An enormous iron core takes up more than 60 percent of the planet's total mass – twice as much as Earth's.

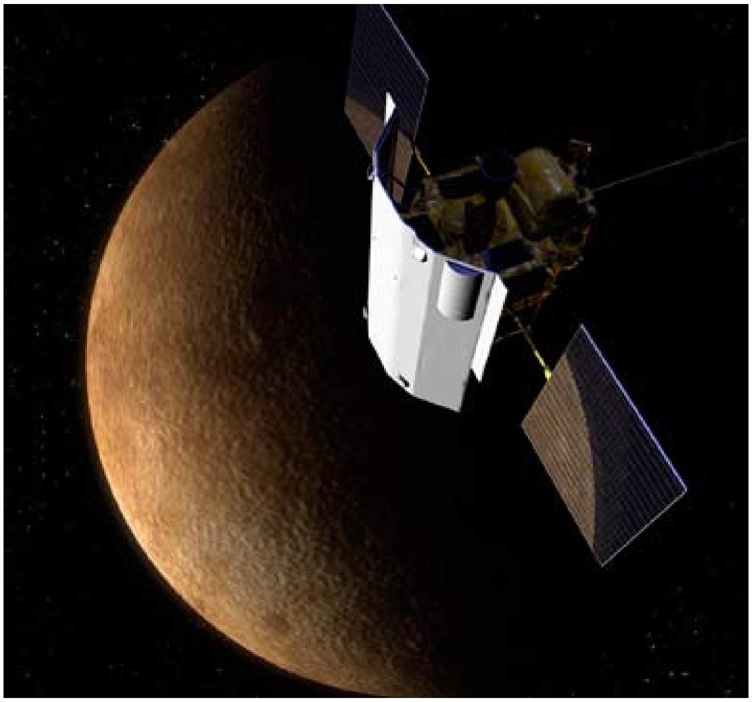
Environment

- Mercury experiences the solar system's largest swing in surface temperatures, from highs above 700° Kelvin (about 800° Fahrenheit) to lows near 90° K (about –300° F).
- Its extremely thin atmosphere contains hydrogen, helium, oxygen, sodium, potassium, and calcium.
- The only inner planet besides Earth with a global magnetic field, Mercury's field is about 100 times weaker than Earth's (at the surface).

Orbit

- The average distance from the Sun is 58 million kilometers (36 million miles), about two-thirds closer to the Sun than Earth is.
- The highly elliptical (elongated) orbit ranges from 46 million kilometers (29 million miles) to 70 million kilometers (43 million miles) from the Sun.
- Mercury orbits the Sun once every 88 Earth days, moving at an average speed of 48 kilometers (30 miles) per second and making it the "fastest" planet in the solar system.
- Because of its slow rotation – Mercury rotates on its axis once every 59 Earth days – and fast speed around the Sun, one solar day on Mercury (from noon to noon at the same place) lasts 176 Earth days, or two Mercury years.
- The distance from Earth (during MESSENGER's orbit) ranges from about 87 million to 212 million kilometers, about 54 million to 132 million miles.

Why Mercury?



Mercury, Venus, Earth, and Mars are the terrestrial (rocky) planets. Among these, Mercury is an extreme: the smallest, the densest (after correcting for self-compression), the one with the oldest surface, the one with the largest daily variations in surface temperature, and the least explored. Understanding this "end member" among the terrestrial planets is crucial to developing a better understanding of how the planets in our solar system formed and evolved. To develop this understanding, the MESSENGER mission, spacecraft, and science instruments are focused on answering six key questions.

Key Science Questions

Question 1: Why is Mercury so dense?

Each of the terrestrial planets consists of a dense iron-rich core surrounded by a rocky mantle, composed largely of magnesium and iron silicates. The topmost layer of rock, the crust, formed from minerals with lower melting points than those in the underlying mantle, either during differentiation early in the planet's history or by later volcanic or magmatic activity. The density of each planet provides information about the relative sizes of the iron-rich core and the rocky mantle and crust, since the metallic core is much denser than the rocky components. Mercury's uncompressed density (what its density would be without compaction of its interior by the planet's own gravity) is about 5.3 grams per cubic centimeter, by far the highest of all the terrestrial planets. In fact, Mercury's density implies that at least 60% of the planet is a metal-rich core, a figure twice as great as for Earth, Venus, or Mars. To account for about 60% of the planet's mass, the radius of Mercury's core must be approximately 75% of the radius of the entire planet!

There are three major theories to explain why Mercury is so much denser and more metal-rich than Earth, Venus, and Mars. Each theory predicts a different composition for the rocks on Mercury's surface. According to one idea, before Mercury formed, drag by solar nebular gas near the Sun mechanically sorted silicate and metal grains, with the lighter silicate particles preferentially slowed and lost to the Sun; Mercury later formed from material in this region and is consequently enriched in metal. This process doesn't predict any change in the composition of the silicate minerals making up the rocky portion of the planet, just the relative amounts of metal and rock. In another theory, tremendous heat in the early nebula vaporized part of the outer rock layer of proto-Mercury and left the planet strongly depleted in volatile elements. This idea predicts a rock composition poor in easily evaporated elements like sodium and potassium. The third idea is that a giant impact, after proto-Mercury had formed and differentiated, stripped off the primordial crust and upper mantle. This idea predicts that the present-day surface is made of rocks highly depleted in those elements that would have been concentrated in the crust, such as aluminum and calcium.

MESSENGER will determine which of these ideas is correct by measuring the composition of the rocky surface. X-ray, gamma-ray, and neutron spectrometers will measure the elements present in the surface rocks and determine if volatile elements are depleted or if elements that tend to be concentrated in planetary crusts are deficient. A visible-infrared spectrometer will determine which minerals are present and will permit the construction of mineralogical maps of the surface. Analysis of gravity and topography measurements will provide estimates of the thickness of Mercury's crust. Together, these measurements will enable MESSENGER to distinguish among the different proposed origins for Mercury's high density and, by doing so, gain insight into how the planet formed and evolved.

Question 2: What is the geologic history of Mercury?

It is more than 30 years since Mariner 10 visited Mercury and still only 45% of Mercury's surface has been imaged by a spacecraft. The part that has been seen appears cratered and ancient, with a resemblance to the surface of Earth's Moon. Slightly younger, less cratered plains sit between the largest old craters. A volcanic origin has been suggested to explain the formation of these plains, and slight color differences between the plains and ancient cratered terrains are consistent with the plains being volcanic. However, the typical resolution of images from Mariner 10 is not high enough to search for diagnostic volcanic surface features to support fully that idea, and thus the origin of the plains remains uncertain.

Mercury's tectonic history is unlike that of any other terrestrial planet. On the surface of Mercury, the most prominent features due to tectonic forces are long, rounded, lobate scarps and cliffs, some over a kilometer in height and hundreds of kilometers in length. These giant scarps are believed to have formed as Mercury cooled and the entire planet contracted on a global scale. Understanding the formation of these scarps thus provides the potential to gain unique insight into the thermal history and interior structure of Mercury.

MESSENGER will bring a variety of investigations to bear on Mercury's geology in order to determine the sequence of processes that have shaped the surface. The X-ray, gamma-ray, and visible-infrared spectrometers will determine the elemental and mineralogical makeup of rock units composing the surface. The camera will image the previously unseen portion of the planet, and the typical imaging resolution for MESSENGER will far surpass that of most Mariner 10 pictures. Nearly all of the surface will be imaged in stereo to determine the planet's global topographic variations and landforms; the laser altimeter will measure the topography of surface features even more precisely in the northern hemisphere. Comparing the topography with the planet's gravity field, measured by tracking the MESSENGER spacecraft, will allow determinations of local variations in the thickness of Mercury's crust. This large breadth and depth of data returned by MESSENGER will enable the reconstruction of the geologic history of Mercury.

Question 3: What is the nature of Mercury's magnetic field?

Mercury's magnetic field and the resulting magnetosphere, caused by the interaction of Mercury's magnetic field with the solar wind, are unique in many ways. Perhaps one of the most noteworthy observations about Mercury's magnetic field is that the small planet has one. Mercury's magnetic field is similar to the "dipole" shape of Earth's magnetic field, which resembles the field that would be produced if there was a giant bar magnet at the center of the planet. In contrast, Venus, Mars, and the Moon do not show evidence for intrinsic dipolar magnetic fields, but the Moon and Mars have evidence for local magnetic fields centered on different rock deposits.

Earth's magnetic field is very dynamic and constantly changes in response to activity of the Sun, including the solar wind and solar flares. We see the effects of these dynamics on the ground as they affect power grids and electronics, causing blackouts and interference with radios and telephones. Mercury's magnetic field was shown by Mariner 10 to experience similar dynamics; understanding those variations will help us understand the interaction of the Sun with planetary magnetospheres in general.

Although Mercury's magnetic field is thought to be a miniature version of Earth's, Mariner 10 didn't measure Mercury's field well enough to characterize it. There is even considerable uncertainty in the strength and source of the magnetic field. Some theories have proposed that Mercury's magnetic field is actually a relic and not actively being generated today. Advocates for an active global magnetic field on Mercury, arising from fluid motions in an outer liquid portion of Mercury's metal core, debate the molten fraction of the core as well as whether the field is driven by compositional or thermal differences. However, these different ideas for the driving force behind Mercury's magnetic field predict slightly different field geometries, so careful measurements by spacecraft can distinguish among current theories.

MESSENGER's magnetometer will characterize Mercury's magnetic field in detail from orbit over four Mercury years (each Mercury year equals 88 Earth days) to determine its exact strength and how its strength varies with position and altitude. The effects of the Sun on magnetic field dynamics will be measured by the magnetometer and by an energetic particle and plasma spectrometer. MESSENGER's highly capable instruments and broad orbital coverage will greatly advance our understanding of both the origin of Mercury's magnetic field and the nature of its interaction with the solar wind.

Question 4: What is the structure of Mercury's core?

As discussed in Questions 1 and 3, Mercury has a very large iron-rich core and a global magnetic field; this information was gathered by the Mariner 10 flybys. More recently, Earth-based radar observations of Mercury have also determined that at least a portion of the large metal core is still liquid. Having at least a partially molten core means that a very small but detectable variation in the spin rate of Mercury has a larger amplitude because of decoupling between the solid mantle and liquid core. Knowing that the core has not completely solidified, even as Mercury has cooled over billions of years since its formation, places important constraints on the planet's thermal history, evolution, and core composition.

However, these constraints are limited due to the low precision of current information on Mercury's gravity field from the Mariner 10 flybys, currently the only gravity measurements available for Mercury. Fundamental questions about Mercury's core remain to be explored, such as what is the composition of the core? A core of pure iron would be completely solid today, due to the high melting point of iron. However, if other elements, such as sulfur, are also present in Mercury's core, even at only a level of a few percent, the melting point is lowered considerably, allowing Mercury's core to remain at least partially molten. Constraining the composition of the core is intimately tied to understanding what fraction of the core is liquid and what fraction has solidified. Is there just a very thin layer of liquid over a mostly solid core or is the core completely molten? Addressing questions such as these can also provide insight into the current thermal state of Mercury's interior, which is very valuable information for determining the evolution of the planet.

Using the laser altimeter, MESSENGER will verify the presence of a liquid outer core by measuring Mercury's libration. Libration is the slow 88-day wobble of the planet around its rotational axis. The libration of the rocky outer part of the planet will be twice as large if it is floating on a liquid outer core than if it is frozen to a solid core. By radio tracking of the spacecraft, MESSENGER will also determine the gravity field with much better precision than accomplished with the Mariner 10 flybys. The libration experiment, when combined with improved measurements of the gravity field, will provide constraints on the size and structure of the core.

Question 5: What are the unusual materials at Mercury's poles?

Mercury's axis of rotation is oriented nearly perpendicular to the planet's orbit, so that in the polar regions sunlight strikes the surface at a near constant grazing angle. Some of the interiors of large craters at the poles are thus permanently shadowed and perpetually very cold. Earth-based radar images of the polar regions show that the floors of large craters are highly reflective at radar wavelengths, unlike the surrounding terrain. Furthermore, the radar-bright regions are consistent with radar observations of the polar cap of Mars and the icy moons of Jupiter, suggesting that the material concentrated in the shadowed craters is water ice. The idea of water ice being stable on the surface of the planet closest to the Sun is an intriguing suggestion.

The temperature inside these permanently shadowed craters is believed to be low enough to allow water ice to be stable for the majority of the observed deposits. Ice from infalling comets and meteoroids could be cold-trapped in Mercury's polar deposits over billions of years, or water vapor might outgas from the planet's interior and freeze at the poles. A few craters at latitudes as low as 72° N have also been observed to contain radar-bright material in their interiors, and at these warmer latitudes, maintaining stable water ice for longer periods of time may be more difficult; a recent comet impact, in the last few million years, delivering water to Mercury may be required. Alternatively, it has been suggested that the radar-bright deposits are not water ice but rather consist of a different material, such as sulfur. Sulfur would be stable in the cold traps of the permanently shadowed crater interiors, and the source of sulfur could either be meteoritic material or the surface of Mercury itself. It has also been proposed that the naturally occurring silicates that make up the surface of Mercury could produce the observed radar reflections when maintained at the extremely low temperatures present in the permanently shadowed craters.

MESSENGER's neutron spectrometer will search for hydrogen in any polar deposits, the detection of which would suggest the polar deposits are water-rich. The ultraviolet spectrometer and energetic particle spectrometer will search for the signatures of hydroxide or sulfur in the tenuous vapor over the deposits. The laser altimeter will provide information about the topography of the permanently shadowed craters. Understanding the composition of Mercury's polar deposits will clarify the inventory and availability of volatile materials in the inner solar system.

Question 6: What volatiles are important at Mercury?

Mercury is surrounded by an extremely thin envelope of gas. It is so thin that, unlike the atmospheres of Venus, Earth, and Mars, the molecules surrounding Mercury don't collide with each other and instead bounce from place to place on the surface like many rubber balls. This is called an "exosphere."

Six elements are known to exist in Mercury's exosphere: (1) hydrogen, (2) helium, (3) oxygen, (4) sodium, (5) potassium, and (6) calcium. The observed exosphere is not stable on timescales comparable to the age of Mercury, and so there must be sources for each of these elements. High abundances of hydrogen and helium are present in the solar wind, the stream of hot, ionized gas emitted by the Sun. The other elements are likely from material impacting Mercury, such as micrometeoroids or comets, or directly from Mercury's surface rocks. Several different processes may have put these elements into the exosphere, and each process yields a different mix of the elements: vaporization of rocks by impacts, evaporation of elements from the rocks due to sunlight, sputtering by solar wind ions, or diffusion from the planet's interior. Variability of the composition of Mercury's exosphere has been observed, suggesting the interaction of several of these processes.

MESSENGER will determine the composition of Mercury's exosphere using its ultraviolet spectrometer and energetic particle spectrometer. The exosphere composition measured by these instruments will be compared with the composition of surface rocks measured by the X-ray, gamma-ray, and neutron spectrometers. As MESSENGER orbits Mercury, variations in the exosphere's composition will be monitored. The combination of these measurements will elucidate the nature of Mercury's exosphere and the processes that contribute to it.

Learn More

For additional, detailed information about the science questions driving the MESSENGER mission, check out the articles posted at: http://messenger.jhuapl.edu/the_mission/publications.html.

Mercury's Visitors

Mariner 10

Most of what we know about Mercury today comes from Mariner 10's three flyby visits in 1974 and 1975. The flybys weren't the NASA mission's only historic moments; Mariner 10 was also the first spacecraft to use the gravitational pull of one planet (Venus) to reach another and the first to study two planets up close.

Carrying two TV cameras with filter wheels, an infrared radiometer, a plasma experiment, a magnetometer, a charged particle detector, extreme ultraviolet spectrometers, and a radio science experiment, Mariner 10 was launched toward Venus by an Atlas Centaur 34 on November 3, 1973. After flying past Venus on February 5, 1974 – and snapping the first close-up images of the planet's upper clouds – the spacecraft headed for Mercury in an orbit around the Sun. That trajectory brought it past Mercury three times – on March 29 and September 21, 1974, and March 16, 1975 – each affording views of the same side, and while the planet was at its farthest point from the Sun.

The spacecraft's closest passes, respectively, occurred at 703 kilometers, 48,069 kilometers, and 327 kilometers (437 to 29,870 to 203 miles), giving it different vantages on approach and departure. Mariner 10 mapped 45 percent of Mercury's surface at a scale of approximately 1 kilometer (0.6 miles), revealing a landscape battered with impact craters and a fascinating mix of smooth and rough terrain; discovered a global magnetic field and a thin atmosphere; and confirmed that Mercury, thanks to a large, iron-rich core, has the highest uncompressed density of any planet.

Mariner 10's reconnaissance whetted scientists' appetites to learn more about the innermost planet – and its results helped form the questions MESSENGER will try to answer three decades later.

Other Links

The Web and your local library (or bookstore) offer several sources of information on the Mariner 10 mission and Mercury, including:

The Voyage of Mariner 10: Mission to Venus and Mercury (James A. Dunne and Eric Burgess, Jet Propulsion Laboratory, SP-424, 1978) – http://history.nasa.gov/SP-424/sp424.htm

Mariner 10 Archive Project (Mark Robinson, Arizona State University) – http://ser.sese.asu.edu/merc.html

The SP-423 Atlas of Mercury On Line (NASA History Web site) – http://history.nasa.gov/SP-423/mariner.htm

Flight to Mercury by Bruce Murray and Eric Burgess, Columbia University Press, 1977 (ISBN 0-231-03996-4)

Mercury by Faith Vilas, Clark Chapman, and Mildred Shapley Matthews, University of Arizona Press, 1988 (ISBN 0-8165-1085-7)

Exploring Mercury by Robert Strom and Ann Sprague, Springer-Praxis Books, 2003 (ISBN 1-85233-731-1)

Future Missions

MESSENGER will soon have company in its study of Mercury. The BepiColombo mission, a collaboration between the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA), will place a pair of spacecraft in orbit around Mercury, one to map the planet and the other to study the magnetosphere. The mission is named for late Italian mathematician and engineer Guiseppe (Bepi) Colombo, who suggested to NASA the flight path that allowed Mariner 10 to fly by Mercury three times. The two spacecraft are scheduled for launch in 2013 and for arrival at Mercury in 2019.

Mission Overview

Cruise Trajectory

The MESSENGER mission takes advantage of an ingenious trajectory design, lightweight materials, and miniaturization of electronics, all developed in the three decades since Mariner 10 flew past Mercury in 1974 and 1975. The compact orbiter, fortified against the searing conditions near the Sun, will investigate key questions about Mercury's characteristics and environment with a set of seven scientific instruments.

On a 4.9-billion mile (7.9-billion kilometer) journey that includes more than 15 loops around the Sun, the spacecraft's trajectory includes one pass by Earth, two by Venus, and three by Mercury, before a propulsive burn will ease it into orbit around its target planet. The Earth flyby in August 2005, along with the Venus flybys in October 2006 and June 2007, used the pull of each planet's gravity to guide MESSENGER toward Mercury's orbit. The Mercury flybys in January 2008, October 2008, and September 2009 adjust MESSENGER's trajectory while also providing opportunities for the spacecraft to gather important science observations in advance of the mission's orbital phase.

The combined effect of the six gravity assists from three planetary bodies and five deterministic Deep Space Maneuvers (DSMs) – using the bipropellant Large Velocity Adjust (LVA) engine of the spacecraft and the influence of the Sun – accelerates the spacecraft from an average speed around the Sun of 29.8 kilometers per second (the Earth's average speed around the Sun) to 47.9 kilometers per second (Mercury's average speed around the Sun).

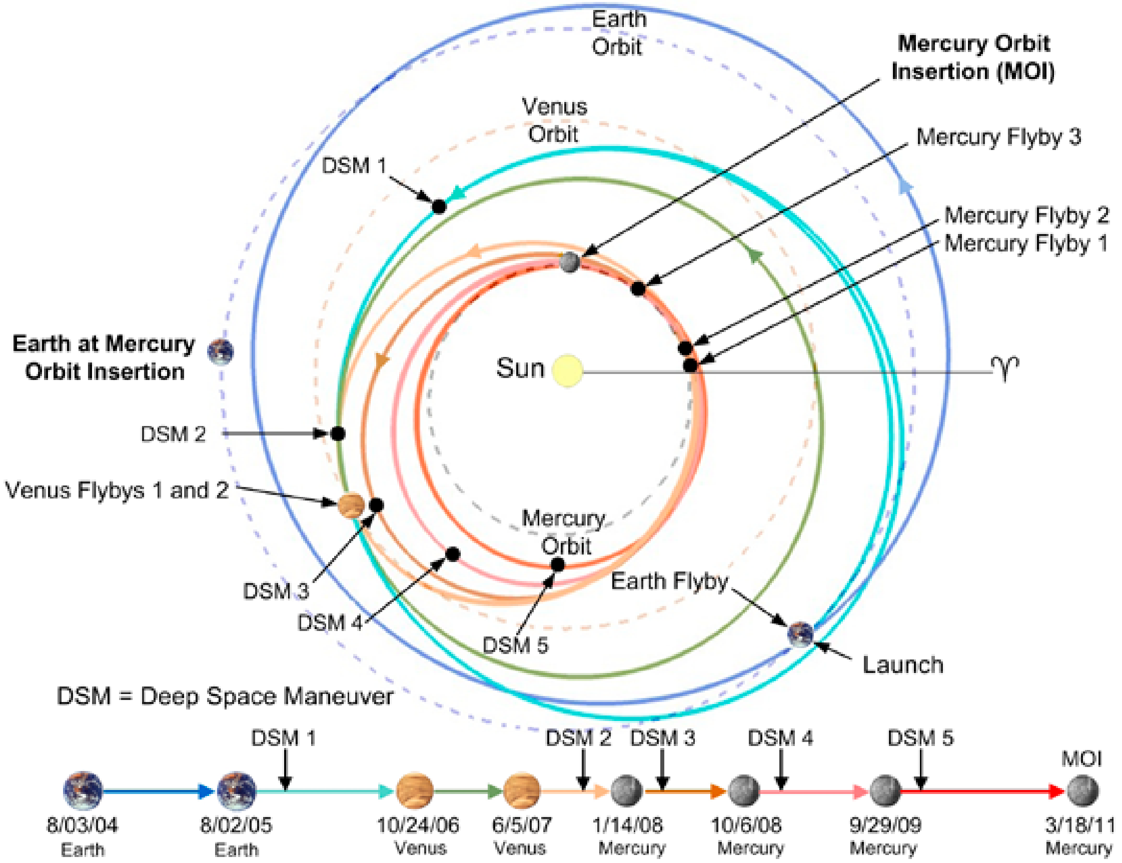
The cruise phase of the mission concludes in March 2011, when the spacecraft will execute the Mercury orbit insertion (MOI) maneuver, slowing the spacecraft from a heliocentric orbit and allowing it to be captured into orbit around Mercury.

Getting a Boost

For a gravity assist, a spacecraft flies close to a planet and trades with the planet's orbital momentum around the Sun. Depending on the relative difference in mass between the planet and the spacecraft, as well as the distance between the two, this exchange of momentum can impart a substantial change in spacecraft speed. Since the spacecraft's mass is negligible compared with the planet's, this process has a negligible effect on the planet's orbit around the Sun. But the spacecraft receives a great boost on the way to its next destination.

Gravity-assist maneuvers can be used to speed a spacecraft up or slow a spacecraft down. Closest approach distance, direction, and the speed of a spacecraft relative to the planet's speed all affect the acceleration and direction change of the spacecraft's trajectory. The greatest change in a spacecraft's speed and direction occurs when a slow-moving spacecraft approaches just above the surface or cloud tops of a massive planet. The least change in a spacecraft's speed and direction occurs when a fast-moving spacecraft approaches a small planet from a great distance.

Earth to Mercury



MESSENGER cruise trajectory from the Earth to Mercury with annotation of critical flyby and maneuver events. View looks down from the ecliptic north pole.

Multiple Flybys

Mariner 10 flew past Venus to reach Mercury, but the idea of multiple Venus/Mercury flybys to help a spacecraft "catch" Mercury and begin orbiting the planet came years later, when Chen-wan Yen of NASA's Jet Propulsion Laboratory developed the concept in the mid-1980s. MESSENGER adopts this mission design approach; without these flybys, MESSENGER would move so fast past Mercury (about 10 kilometers per second) that no existing propulsion system could slow it down sufficiently for it to be captured into orbit.

Launch

MESSENGER launched from complex 17B at Cape Canaveral Air Force Station, Florida, on a three-stage Boeing Delta II expendable launch vehicle on August 3, 2004. The Delta II 7925-H (heavy lift) model was the largest allowed for NASA Discovery missions. It features a liquid-fueled first stage with nine strap-on solid boosters, a second-stage liquid-fueled engine, and a third-stage solid-fuel rocket. With MESSENGER secured in a 9.5-meter (31-foot) fairing on top, the launch vehicle was about 40 meters (or 130 feet) tall.

The launch vehicle imparted a launch energy per mass (usually denoted by C^3 and equal to the excess over what is required for Earth escape) of approximately 16.4 km^2/sec^2 to the spacecraft, setting up the spacecraft for a return pass by the Earth approximately one year from launch.

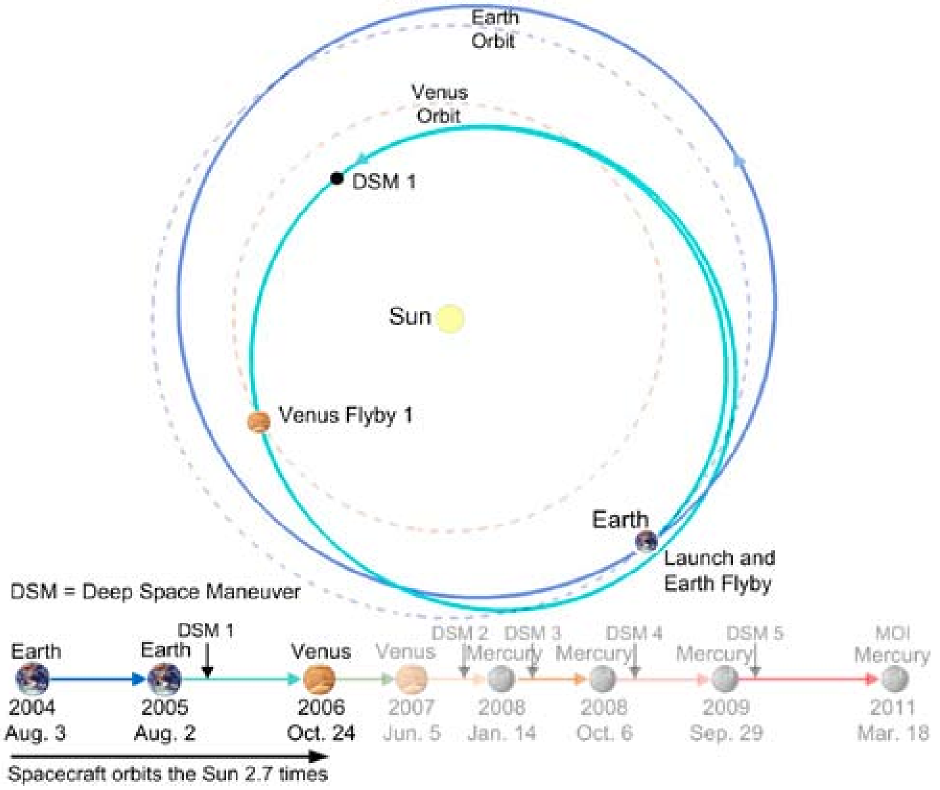
MESSENGER launch from Cape Canaveral Air Force Station, Florida, on August 3, 2004, at 2:15 a.m. EDT.

Team members in the MESSENGER Mission Operations Center at APL watch the spacecraft launch from Cape Canaveral. The team began operating the spacecraft less than an hour later, after MESSENGER separated from the launch vehicle.

Earth Flyby Highlights

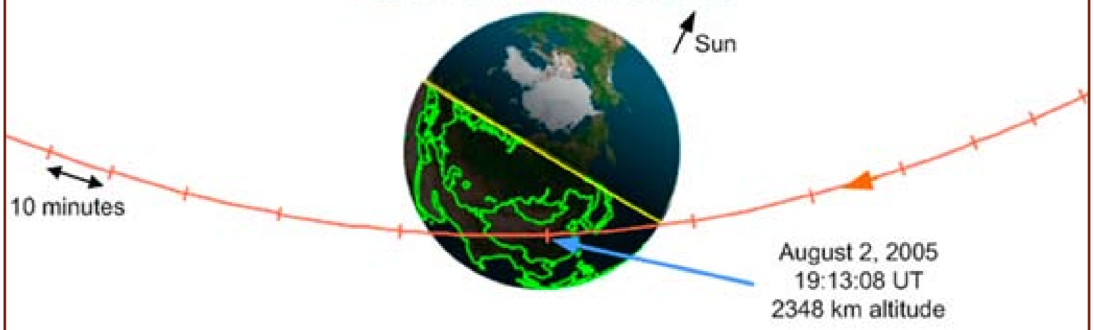
MESSENGER swung by its home planet on August 2, 2005, for a gravity assist that propelled it deeper into the inner solar system. MESSENGER's systems performed flawlessly as the spacecraft swooped around Earth, coming to a closest approach point of about 1,458 miles (2,347 kilometers) over central Mongolia at 3:13 p.m. EDT. The spacecraft used the tug of Earth's gravity to change its trajectory significantly, bringing its average orbital distance nearly 18 million miles closer to the Sun and sending it toward Venus for gravity assists in 2006 and 2007.

Earth to Venus



North ecliptic pole view of the trajectory between Earth and the first Venus flyby. Dashed lines depict the orbits of Earth and Venus. Timeline fading helps emphasize primary events.

Earth northern hemisphere



View of the Earth flyby trajectory from above northern Asia. Major country borders are outlined in green on Earth's night side. The yellow line marks the position of the day/night or dawn/dusk terminator.

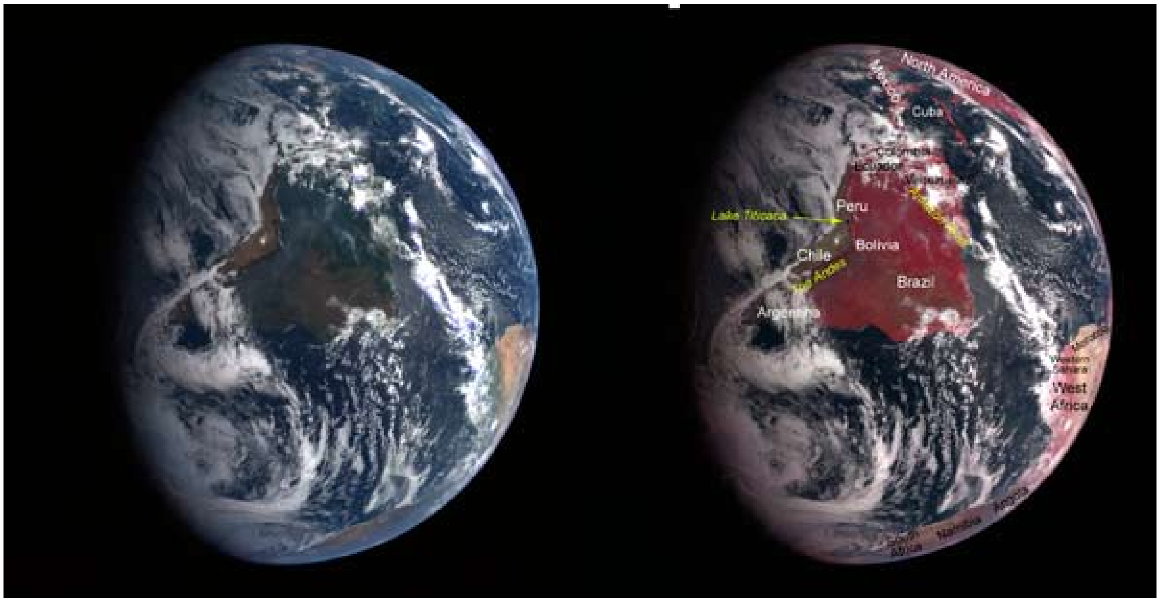
MESSENGER's main camera snapped several approach shots of Earth and the Moon, including a series of color images that science team members strung into a "movie" documenting MESSENGER's departure. On approach, the atmospheric and surface composition spectrometer also made several scans of the Moon in conjunction with the camera observations, and during the flyby the particle and magnetic field instruments spent several hours making measurements in Earth's magnetosphere.

The close flyby of Earth and the Moon allowed MESSENGER to give its two cameras, together known as the Mercury Dual Imaging System (MDIS), a thorough workout. The images helped the team understand fully how the cameras operate in flight in comparison with test results obtained in the laboratory before launch. Images were taken in full color and at different resolutions, and the cameras passed their tests.

Not only were these pictures useful for carefully calibrating the imagers for the spacecraft's Mercury encounters, they also offered a unique view of Earth. Through clear skies over much of South America, features such as the Amazon, the Andes, and Lake Titicaca are visible, as are huge swaths of rain forest.

The pictures from MESSENGER's flyby of Earth include "natural" color and infrared views of North and South America; a peek at the Galápagos Islands through a break in the clouds; and a movie of the rotating Earth, taken as MESSENGER sped away from its home planet.

Twins Image

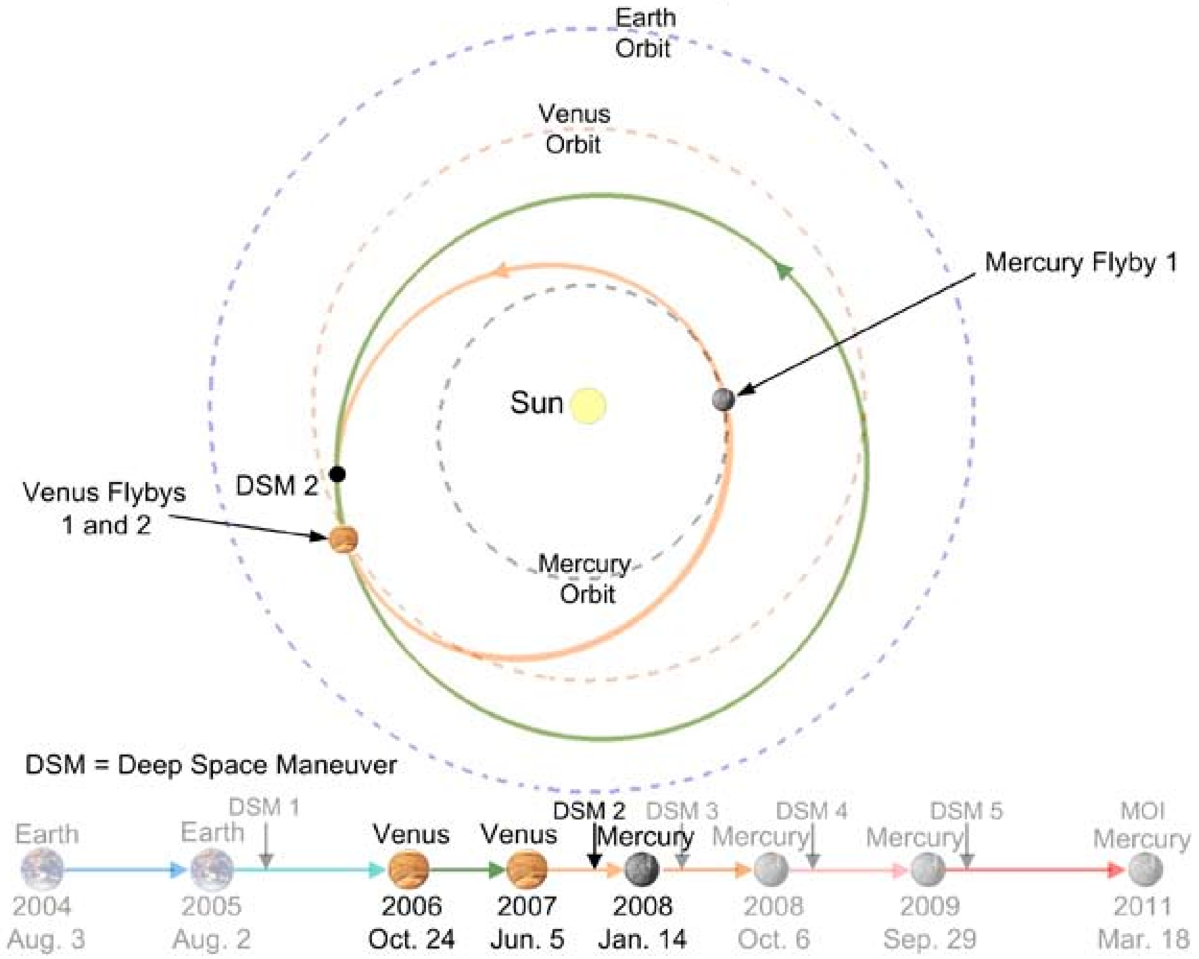


Using various combinations of filters in the optical path, MESSENGER's camera can obtain a mix of red, green, and blue (RGB) light in various proportions to create a full spectrum of colors. Infrared images are visualized by substituting one of the RGB components. On the left is a "normal" color image of the Earth. On the right, the red component is the 750-nm (infrared) band, and green and blue are formed from the 630-nm and the 560-nm bands. Despite the substitution of only one band, the results are dramatically different. Continental areas are mostly red due to the high reflectance of vegetation in the near-infrared. Short-wavelength light (blue) is easily scattered in Earth's atmosphere, producing our blue skies, but also obscuring the surface from MESSENGER's viewpoint. Infrared light is not easily scattered, so images of the Earth remain sharp. The red coloring in the center of the image is a reflection of the Brazilian rain forests and other vegetation in South America.

Venus Gravity Assists

MESSENGER has flown by Venus twice using the tug of the planet's gravity to change its trajectory, to shrink the spacecraft's orbit around the Sun and bring it closer to Mercury.

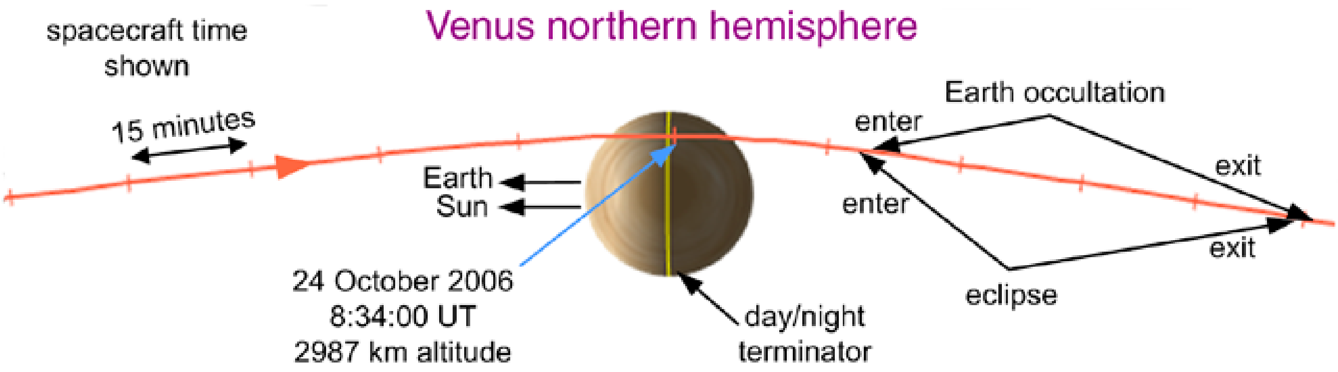
Venus to Mercury



North ecliptic pole view of the trajectory between the first Venus flyby and the first Mercury flyby. Dashed lines depict the orbits of Earth, Venus, and Mercury. Timeline fading helps emphasize primary events.

During the first Venus flyby on October 24, 2006, the spacecraft came within 2,987 kilometers (1,856 miles) of the surface of Venus. Shortly before the encounter, MESSENGER entered superior solar conjunction, where it was on the opposite side of the Sun from Earth and during which reliable communication between MESSENGER and mission operators was not possible. In addition, during the flyby the spacecraft experienced the mission's first and longest eclipse of the Sun by a planet. During the eclipse, which lasted approximately 56 minutes, the spacecraft's solar arrays were in the shadow of Venus and MESSENGER operated on battery power.

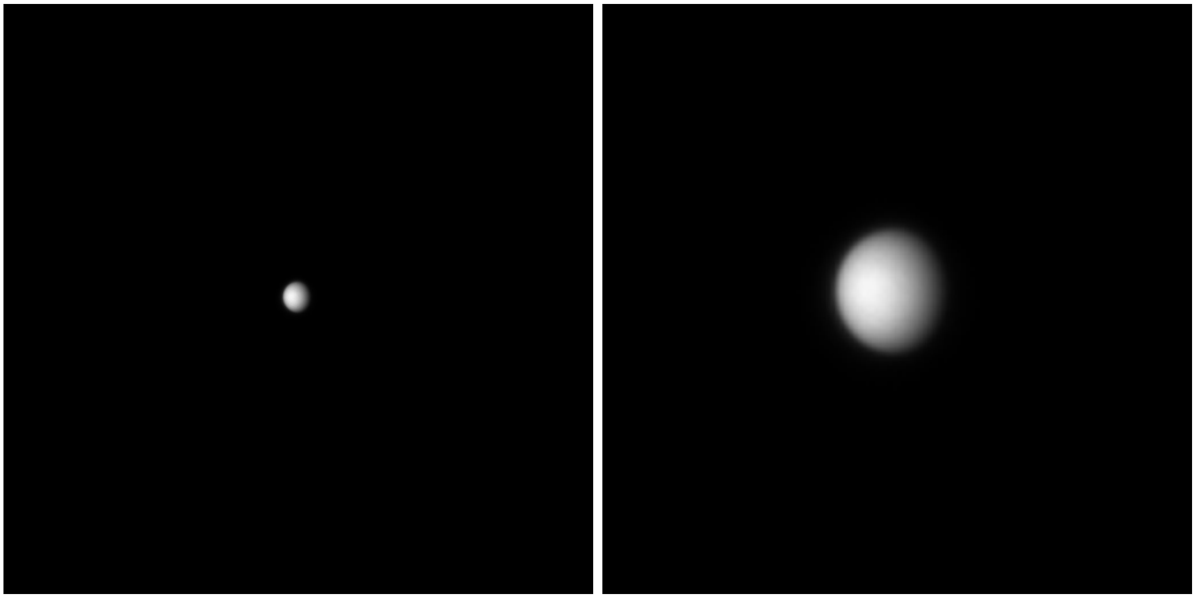
Venus Flyby 1



View of the first Venus flyby trajectory from above the planet's northern pole. The yellow line marks the position of the day/night or dawn/dusk terminator. Closest approach time listed is in local spacecraft time, not accounting for the one-way light time for the signals to reach the Earth.

As a result of this confluence of orbital geometry, the team did not make any scientific observations. But a few weeks before the flyby, MDIS snapped pictures of Venus (see below) from a distance of about 16.5 million kilometers (10.3 million miles). Despite the low resolution of the images, it's possible to see that Venus is shrouded in a thick blanket of clouds that hides its surface.

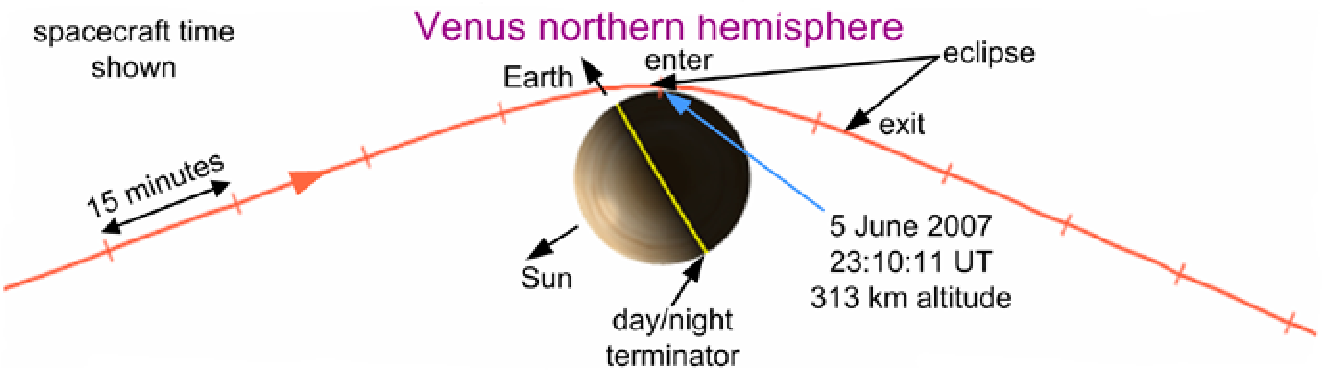
Approaching Venus



Images of Venus on approach to MESSENGER's first Venus flyby on October 24, 2006.

MESSENGER swung by Venus for the second time on June 5, 2007, speeding over the planet's cloud tops at a relative velocity of more than 30,000 miles per hour and passing within 210 miles of its surface near the boundary between the lowland plains of Rusalka Planitia and the rifted uplands of Aphrodite Terra. The maneuver sharpened the spacecraft's aim toward the first encounter with Mercury and presented a special opportunity to calibrate several of its science instruments and learn something new about Earth's nearest neighbor.

Venus Flyby 2



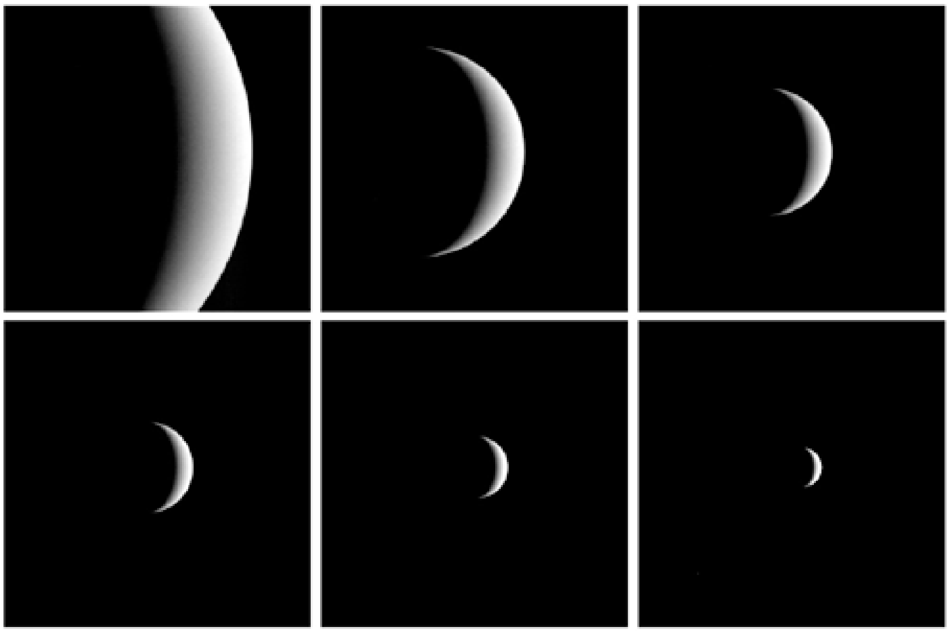
View of the second Venus flyby trajectory from above the planet's northern pole. The yellow line marks the position of the day/night or dawn/dusk terminator. Closest approach time listed is in local spacecraft time, not accounting for the one-way light time for the signals to reach the Earth.

Venus 2 Approach

Approach image taken through the 630-nm filter (stretched). Global circulation patterns in the clouds are clearly visible.

All of the MESSENGER instruments operated during the flyby. The camera system imaged the night side in near-infrared bands and obtained color and higher-resolution monochrome mosaics of both the approaching and departing hemispheres. The Ultraviolet and Visible Spectrometer on the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) instrument obtained profiles of atmospheric species on the day and night sides as well as observations of the exospheric tail on departure.

Leaving Venus

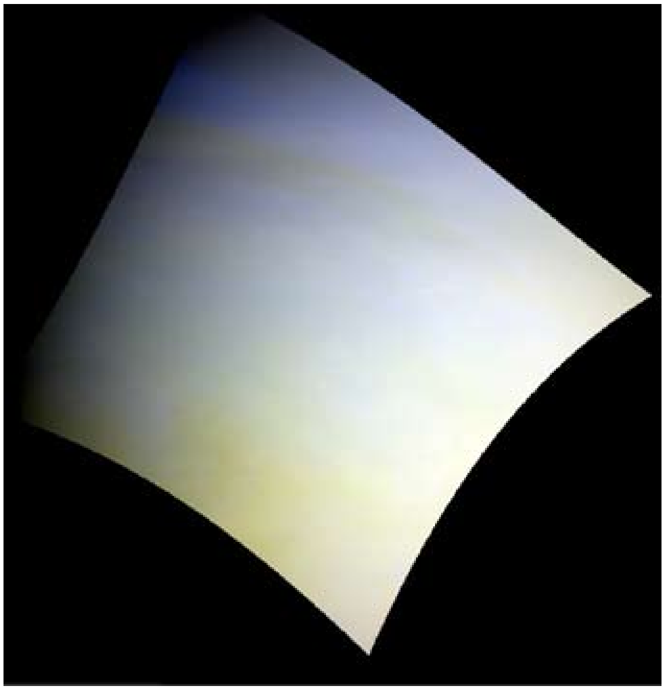


MDIS departure sequence, 480-nm filter.

The MASCS Visible and Infrared Spectrograph observed the Venus dayside near closest approach to gather compositional information on the upper atmosphere and clouds, and the Mercury Laser Altimeter (MLA) carried out passive radiometry at 1,064 nm and attempted to range to the Venus upper atmosphere and clouds for several minutes near closest approach. The Gamma-Ray and Neutron Spectrometer (GRNS) observed gamma-rays and neutrons from Venus' atmosphere, providing information for planning the upcoming Mercury flybys and for calibration from a source of known composition.

That the European Space Agency's Venus Express mission was operating at the time of the flyby permitted the simultaneous observation of the planet from two independent spacecraft, a situation of particular value for characterization of the particle-and-field environment at Venus. MESSENGER's Energetic Particle and Plasma Spectrometer (EPPS) observed charged particle acceleration at the Venus bow shock and elsewhere, and the Magnetometer (MAG) measured the upstream interplanetary magnetic field (IMF), bow shock signatures, and pick-up ion waves as a reference for energetic particle and plasma observations by both spacecraft. The encounter also enabled two-point measurements of IMF penetration into the Venus ionosphere, primary plasma boundaries, and the near-tail region.

Venus Clouds in Color



Color composite calibration frame of Venus' clouds, centered at 17°N, 260°E.

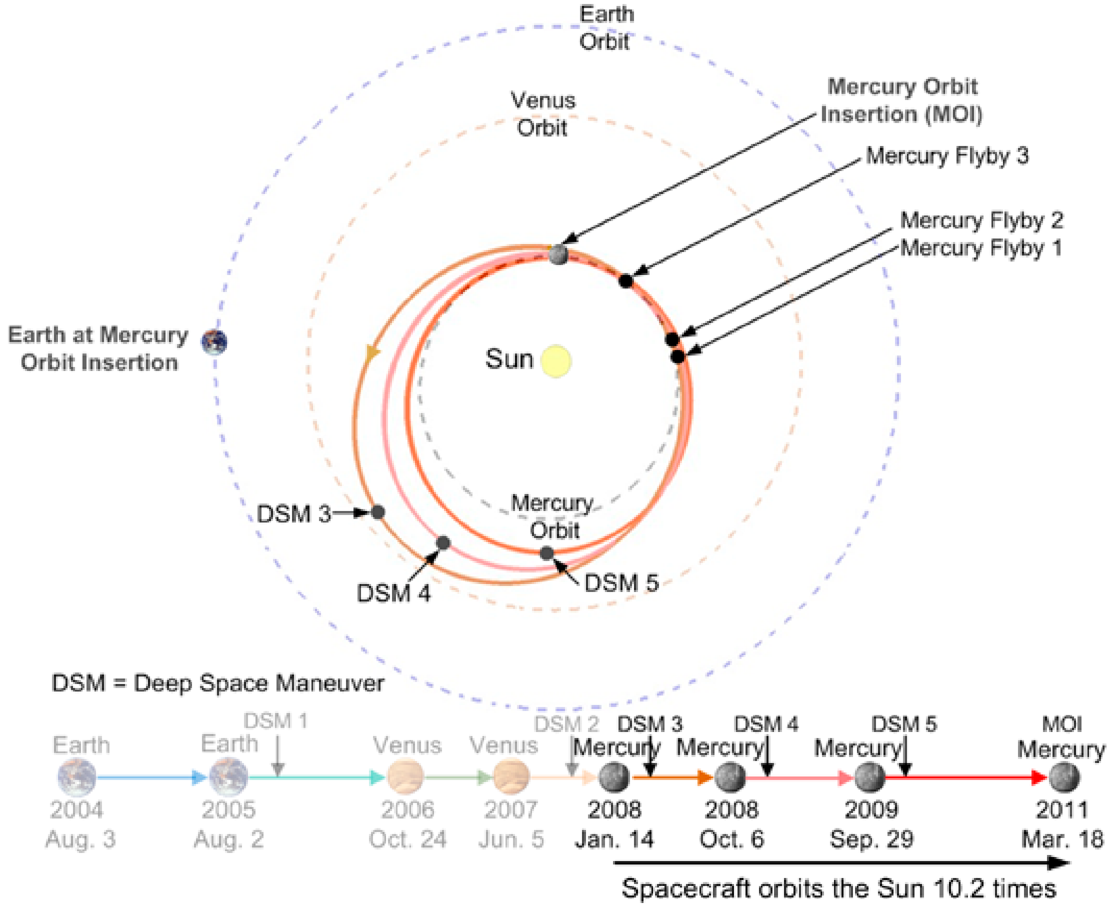
Interplanetary Golf

The MESSENGER spacecraft flew within 1.7 kilometers (1.05 miles) of the targeted aim point during the approach to the second Venus encounter, the interplanetary equivalent of hitting a hole-in-one.

Flying by Mercury

Three 200-kilometer (124-mile) minimum-altitude Mercury flybys are scheduled to put MESSENGER in position to enter Mercury orbit in mid-March 2011. A pre-determined course correction maneuver – a Deep-Space Maneuver (DSM) using the main Large Velocity Adjust (LVA) engine – is scheduled approximately two months following each flyby to further adjust spacecraft trajectory in preparation for the eventual capture into orbit around Mercury.

Mercury Flybys

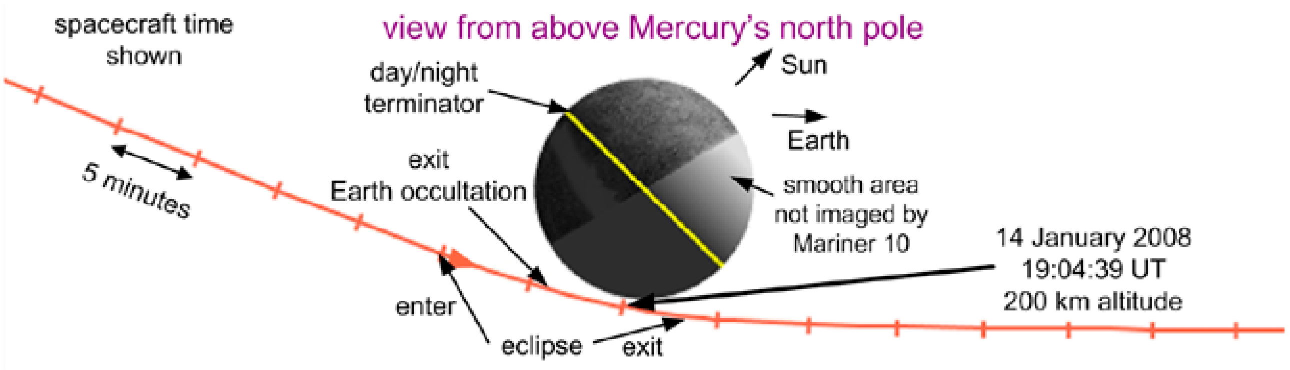


North ecliptic pole view of the trajectory between the first Mercury flyby and Mercury orbit insertion. Dashed lines depict the orbits of Earth, Venus, and Mercury. Timeline fading helps emphasize primary events.

During the flyby the spacecraft will depart looking back toward sunlit views of the planet. MESSENGER's instruments will view each side of the hemisphere of Mercury not seen by Mariner 10 soon after reaching minimum altitude.

After the three flybys of Mercury, MESSENGER will have mapped nearly the entire planet in color, imaged most of the areas not seen by Mariner 10, and measured the composition of the surface, atmosphere, and magnetosphere. Of the three flybys, the first provides the most opportune geometry for scientific observation and discovery. In addition to returning the first new spacecraft data from Mercury in more than 30 years, this flyby will add significantly to the scientific record of the planet. In contrast to the orbital phase of the mission, the closest approach point to the planet – a 200 kilometer altitude from the surface – will occur near the planet's equator and pass by longitudes not encountered at close range by Mariner 10. This approach provides unique vantages to gather high-resolution images of the low-to-mid-latitude regions of the planet not previously seen in detail as well as measurements of the magnetic and gravitational fields.

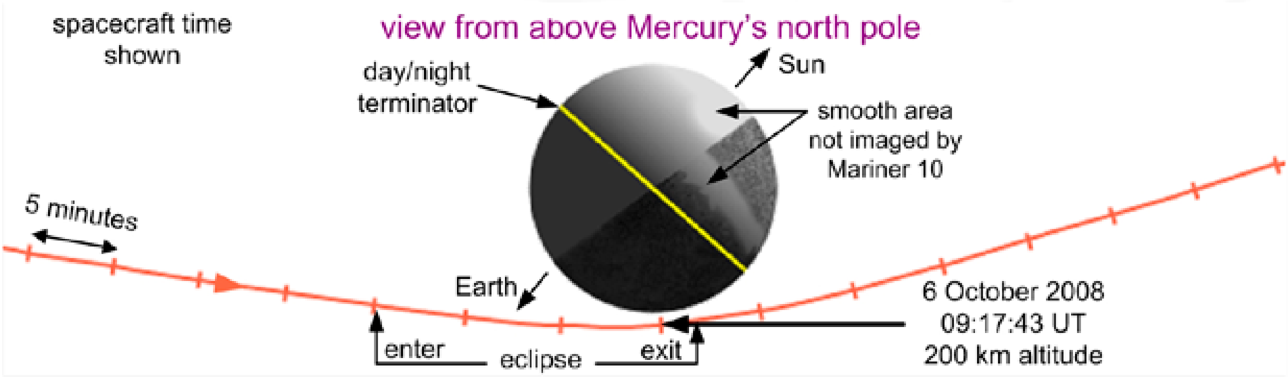
Mercury Flyby 1



View of the first Mercury flyby trajectory from above the planet's northern pole. The yellow line marks the position of the day/night or dawn/dusk terminator. Closest approach time listed is in local spacecraft time, not accounting for the one-way light time for the signals to reach the Earth.

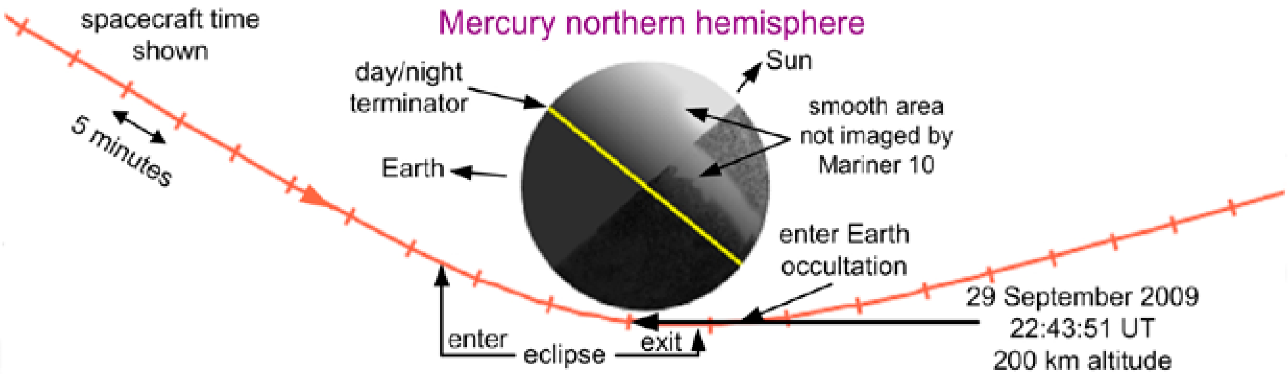
The second and third flybys of the planet offer similar flyby trajectories, also passing near low-to-mid latitudes, but at longitudes that have been previously mapped by the Mariner 10 spacecraft. These flyby opportunities, in addition to increasing the heliocentric orbital velocity of the spacecraft, will expand the knowledge gained from the first flyby.

Mercury Flyby 2



View of the second Mercury flyby trajectory from above the planet's northern pole. The yellow line marks the position of the day/night or dawn/dusk terminator. Closest approach time listed is in local spacecraft time, not accounting for the one-way light time for the signals to reach the Earth.

Mercury Flyby 3



View of the third Mercury flyby trajectory from above the planet's northern pole. The yellow line marks the position of the day/night or dawn/dusk terminator. Closest approach time listed is in local spacecraft time, not accounting for the one-way light time for the signals to reach the Earth.

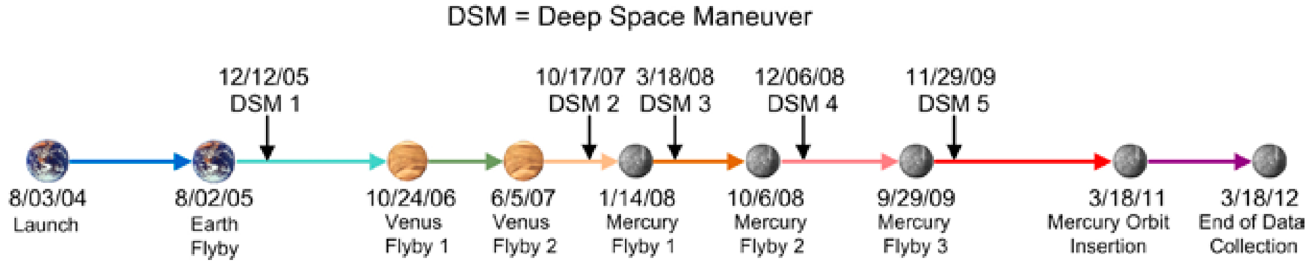
Terra Incognita

During its three flybys of Mercury in 1974-1975, the Mariner 10 spacecraft imaged approximately 45% of the visible surface. Although radar and visible images of portions of the planet not viewed by Mariner 10 have been made from Earth-based observatories, MESSENGER's first Mercury flyby will reveal about 50% of the side of the planet never before seen in detail from a spacecraft.

MESSENGER's Deep Space Maneuvers

In conjunction with the six planetary flybys, MESSENGER's complex 6.6-year cruise trajectory includes more than 40 anticipated trajectory-correction maneuvers (TCMs). These TCMs include five deterministic Deep-Space Maneuvers (DSMs), which use the spacecraft's bipropellant Large Velocity Adjust (LVA) engine. In addition to imparting a combined spacecraft change in velocity of more than 1 kilometer per second, MESSENGER's DSMs are the primary method targeting the spacecraft before each planetary flyby (except the second Venus flyby). Smaller velocity adjustment maneuvers that use the propulsion system's monopropellant thrusters fine-tune the trajectory between the main DSMs and the gravity-assist flybys of the planets.

Mercury Flyby 3



Timeline of deterministic Deep Space Maneuvers for the MESSENGER spacecraft over the entire cruise phase of the mission. Additional statistical "fine-tune" maneuvers not listed.

On December 12, 2005, MESSENGER successfully fired its bipropellant LVA engine for the first time, completing the first of the five critical deep space maneuvers (DSM-1). The maneuver, just over eight minutes long, changed MESSENGER's speed by approximately 316 meters per second (706 miles per hour), placing the spacecraft on target for the first Venus flyby on October 24, 2006.

This maneuver was the first to rely solely on the LVA, the largest and most efficient engine of the propulsion system. Maneuvers performed with the LVA use about 30% less total propellant mass – both fuel and oxidizer – than the other thrusters, which use monopropellant fuel only. Approximately 100 kilograms of bipropellant (both fuel and oxidizer), about 18 percent of MESSENGER's total on-board propellant, was used to complete DSM-1.

On October 17, 2007, MESSENGER completed its second critical DSM – 155 million miles (250 million kilometers) from Earth – successfully firing the LVA again to change the spacecraft's trajectory and target it for its first flyby of Mercury on January 14, 2008.

The maneuver, just over five minutes long, consumed approximately 70 kg of bipropellant (both fuel and oxidizer), changing the velocity of the spacecraft by approximately 226 meters per second (505 miles per hour).

The next two DSMs, one in March 2008 and the other in December 2008, will be used to target the next two gravity-assist flybys of Mercury in October 2008 and September 2009, respectively. The last DSM, in November 2009, will be used to set the initial conditions for the final Mercury orbit insertion (MOI) maneuver on March 2011.

MESSENGER's Large Gas Tank

To support the five DSMs and final Mercury orbit insertion maneuver, the propulsion system was designed to impart more than 2.2 kilometers per second of velocity change to the spacecraft over the life of the mission. To contain this amount of energy and still be able to launch the spacecraft, over 54% of the spacecraft's launch mass was liquid propellant – fuel and oxidizer.

Science Orbit: Working at Mercury

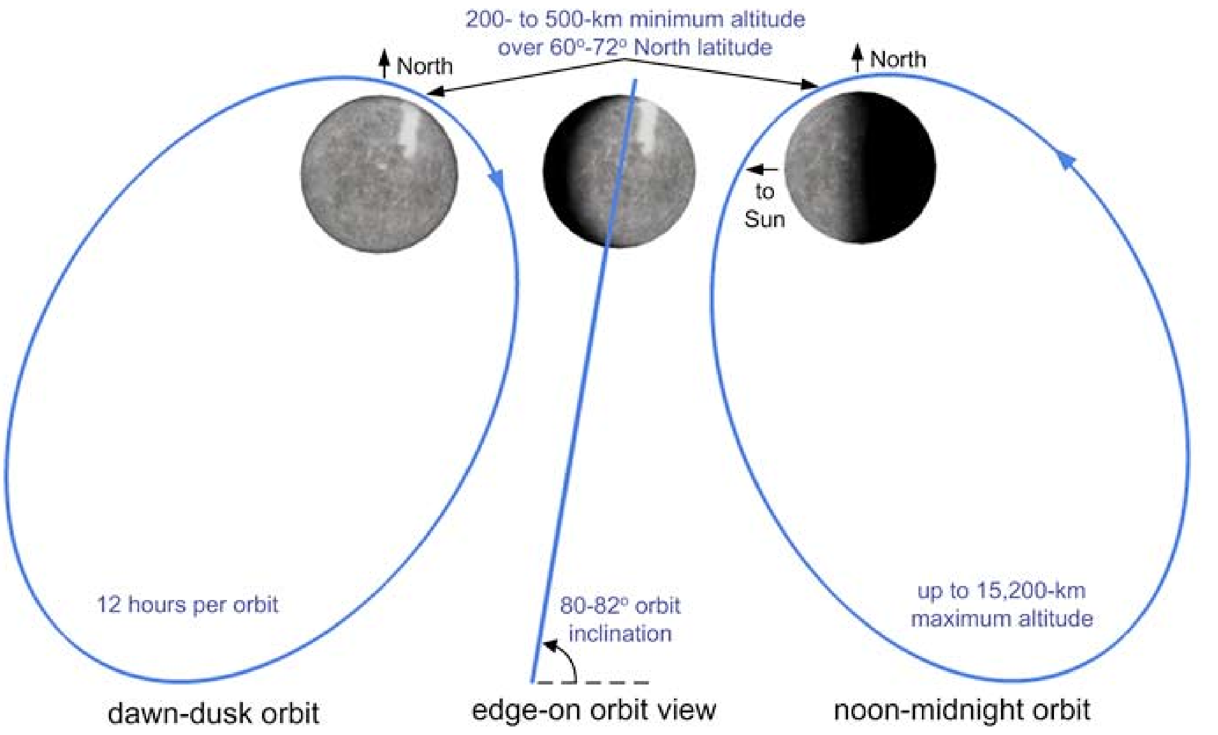
For one year MESSENGER will operate in a highly elliptical (egg-shaped) orbit around Mercury, a nominal 200 kilometers (124 miles) above the surface at the closest point and 15,193 kilometers (9,440 miles) at the farthest. The plane of the orbit is inclined 80° to Mercury's equator, and the low point in the orbit ("periapsis") comes at 60° N latitude. MESSENGER will orbit Mercury twice every 24 hours.

Orbit insertion occurs in March 2011. Using 30 percent of its initial propellant load, MESSENGER will fire its Large Velocity Adjust (LVA) engine and slow down by approximately 860 meters per second (1,924 miles per hour), coming to a virtual stop relative to Mercury. This braking maneuver will be executed in two parts: the first maneuver (lasting about 14 minutes) places the spacecraft in a stable orbit and the second maneuver, a much shorter "cleanup" maneuver, is executed three days later near the orbit's lowest point.

MESSENGER's 12-month orbital mission covers two Mercury solar days; one Mercury solar day, from noon to noon, is equal to 176 Earth days. MESSENGER will obtain global mapping data from the different instruments during the first day and focus on targeted science investigations during the second.

While MESSENGER circles Mercury, the planet's gravity, the Sun's gravity, and radiation pressure from the Sun will slowly and slightly change the spacecraft's orbit. Once every Mercury year (or 88 Earth days) MESSENGER will carry out a pair of maneuvers to reset the orbit to its original size and shape.

Spacecraft Orbit at Mercury



MESSENGER operational orbit at Mercury.

Mission Operations

MESSENGER's mission operations are conducted from the Space Science Mission Operations Center (MOC) at the Johns Hopkins University Applied Physics Laboratory in Laurel, Md., where the spacecraft was designed and built. Flight controllers and mission analysts monitor and operate the spacecraft, working closely with the multi-institutional science team, the mission design team at APL, and the navigation team at KinetX, Inc., based in Simi Valley, Calif. Mission operators and scientists work together to plan, design, and test commands for MESSENGER's science instruments. Working with the mission design and navigation teams, the operators build, test, and send the commands that fire MESSENGER's propulsion system to refine its path to and around Mercury.

Like all NASA interplanetary missions, MESSENGER relies on the agency's Deep Space Network (DSN) of antenna stations to track and communicate with the spacecraft. The stations are located in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. All three complexes communicate directly with the control center at NASA's Jet Propulsion Laboratory, Pasadena, Calif., which in turn communicates with the MESSENGER Mission Operations Center. Typical DSN coverage for MESSENGER includes three 8-hour contacts a week during the cruise phase and twelve 8-hour sessions per week during the orbit at Mercury.

The Science Operations Center, also located at APL, works with the mission operations team to plan instrument activities, as well as validate, distribute, manage, and archive MESSENGER's science data.

Science during Mercury Flyby 1

On January 14, 2008, the MESSENGER spacecraft has its first encounter with its target destination, Mercury, and gets a taste for bigger events to come. This flyby provides the first opportunity to continue the scientific investigation of Mercury begun with the Mariner 10 mission. Scientists have labored over the data from Mariner 10's three flybys for three decades, incorporating insights from other planetary missions and Earth-based observations and formulating new questions about the planet nearest the Sun and the evolution of the terrestrial planets as a group. Such labors led to the six questions that frame the MESSENGER mission and the initial proposal of the mission itself in 1996.

The MESSENGER team will begin to answer those questions with the first flyby, one of four encounters leading up to an orbital study of this enigmatic planet in March 2011. These flybys – driven by orbital mechanics and technological and launch vehicle constraints – will provide a unique perspective on Mercury, including views of terrain not seen by Mariner 10 and other investigations that have been enabled by technological advances in instrumentation. Data from the flybys will lay the groundwork for achieving the mission's science goals.

The top priority of the first Mercury flyby is the gravity assist required for eventual orbit insertion. But the unique trajectories of all three flybys - characterized by a low-altitude pass at equatorial latitudes, in contrast to the highly elliptical, nearly polar orbit that the spacecraft will eventually assume around the planet - provide opportunities for scientific measurements not possible during the orbital phase of this exciting mission. While not "requirements" for mission success in an engineering sense, the flybys provide special opportunities. On this first pass, for example, the entire science payload will make measurements of the mission's intended target. The data returned will give the science community a glimpse into the exciting secrets that will be explored in the subsequent flybys and orbital phase, and allow the MESSENGER Science Team to optimize further those later measurements.

Probing Mercury's Mysteries

The MESSENGER mission – from its conception as a voyage of scientific exploration and discovery – focuses on six key questions regarding Mercury's nature and evolution:

Why is Mercury so dense?

What is the geologic history of Mercury?

What is the nature of Mercury's magnetic field?

What is the structure of Mercury's core?

What are the unusual materials at Mercury's poles?

What volatiles are important at Mercury?

Density. Perhaps the most fundamental of the science questions regarding Mercury is how it formed with such a large metal core, required to account for the planet's anomalously high bulk density. Mercury's core is such a large fraction of its mass that the acceleration due to gravity is almost exactly the same at the surface of Mercury and Mars, even though the diameter of Mars is 40% larger than that of Mercury. (Fact: a person would "weigh" the same on both planets – and about 2/5 their weight on Earth.)

The clues to understanding how Mercury formed mostly of metal are to be found in the composition of the rocky materials on Mercury's surface. This first flyby will provide the first measurements of the mineralogical and elemental composition of Mercury's surface. Moreover, these measurements will be taken of regions near the equator at spatial resolutions not attainable at those latitudes during the orbital phase. Both the visible-near infrared and the ultraviolet-visible spectrometers will be observing the surface to provide reflectance spectra that will indicate mineral composition. The gamma-ray, X-ray, and neutron spectrometers will be making measurements that will provide insight into elemental composition. These measurements will provide the first indications of how this metal-rich planet likely formed. Theories for Mercury's unusually metal-rich composition include: (i) loss of lighter rocky materials to the Sun in the early circumsolar disk of gas and dust before the planets formed; (ii) vaporization of the outer rocky layer of an early Mercury by the hot solar nebula; or (iii) collision of a large proto-planet with Mercury that removed most of Mercury's outer rocky shell.

History. Additional clues to Mercury's formation and evolution can be found in the many landforms and geological features on the surface. Mariner 10 imaged only about 45% of Mercury's surface, and while large portions of the rest of Mercury have been imaged from Earth in both visible light and radar at comparatively coarse resolution, MESSENGER will provide the first detailed global view.

During this flyby MESSENGER will collect the first spacecraft-based images of the portion of the planet not seen by Mariner 10; these will include high-spatial-resolution images near the equator that will not be possible during orbital operations. The first altimetric measurements will be returned from the probe's laser altimeter, again along an equatorial region that will not be viewed at low altitude during the orbital phase. The first stereo and gravity field measurements will also be part of the science returned during this initial encounter. The color images that are part of the observation set, coupled with the information gathered by the spectrometers, will provide deeper insights into Mercury's crustal history. In addition to providing unprecedented detail on surface geology, including the first complete view of the 1300-km-diameter Caloris impact basin, these measurements will provide the context for detailed interpretation of the elemental and mineralogical measurements.

Magnetism. One of the biggest surprises from Mariner 10's encounter with Mercury was the detection of a global magnetic field, which appears to be dipolar, as is Earth's field. The brief glimpses of the magnetic field of Mercury accorded by the first and third Mariner 10 flybys were insufficient to provide details of field orientation and structure. A planetary magnetic dynamo, thought to be the origin of Mercury's magnetic field, is a closed loop of electrical conductors in which current is generated as the conductors are mechanically pulled across a magnetic field. This current, in turn, along with other motion involving planetary rotation, is responsible for the field across which the conductors move. The precise mechanism for generating such a dynamo differs among the planets, but Mercury is the most Earth-like of the planets with internal fields, so detailed study of the field at Mercury should provide insight into Earth's own dynamo.

The mapping of the planet's magnetic field will begin in January with low-altitude measurements near the equatorial region. These measurements will complement those obtained during the orbital phase. The magnetometer will also make observations farther from the planet that will provide glimpses into the field's dynamical interaction with the solar wind, which produces a "magnetotail" and other magnetospheric phenomena.

Core. If Mercury's core is pure iron, it should have solidified long ago. However, the magnetic field observations and the ground-based radar detection of Mercury's forced libration in longitude indicate that Mercury has a molten outer core.

During this flyby, Doppler measurements taken with the spacecraft's telecommunication system will provide a first glimpse into Mercury's gravity field structure. These measurements will refine the values of the second-order gravity coefficients, C_{20} and C_{22}, representing the gravitational oblateness and equatorial ellipticity, respectively. MESSENGER measurements should provide a significant update to those taken by Mariner 10 tracking. These measurements, combined with recent ground-based radar measurements, will significantly refine our knowledge of the size and extent of the planet's liquid core.

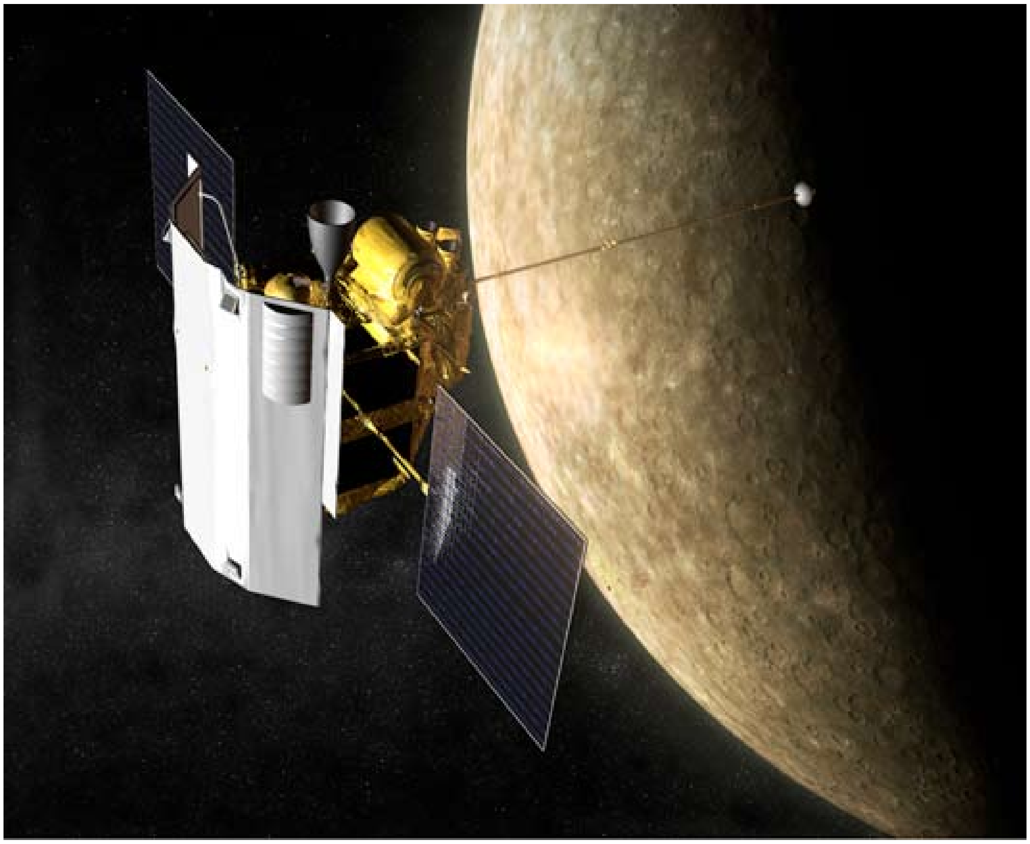
Polar Deposits. Current expectations are that most of the data that will determine the nature of polar deposits will come from the orbital tour, but there can always be surprises when measurements not possible before are made. The first Mercury flyby is equatorial and will not provide an opportunity to view the polar regions directly, but ultraviolet emissions and/or plasma composition changes detected during the flyby may provide important clues about these enigmatic features prior to the orbital phase of the mission.

Volatiles. A significant discovery by Mariner 10 was detection of the presence of a thin, tenuous atmosphere at Mercury comprised of the elements hydrogen, helium, and oxygen. Ground-based measurements have extended the known elements in the exosphere to sodium, potassium, and calcium and have shown that the abundances of these materials strongly vary both spatially and temporally. All of these species are "volatiles" - materials that have low boiling points and so tend to vaporize at low temperatures. In the outer solar system, where temperatures are low, the term "volatiles" refers to surface ices. For the terrestrials planets, volatiles refer to materials with low(er) melting points such as sodium and potassium, as compared with high-melting-point, or refractory, materials.

MESSENGER's first encounter with Mercury provides an opportunity to get a jump start on the mapping of the exosphere with both ultraviolet observations and with energetic particle and plasma measurements of the atmospheric regions. In addition, the unique trajectory of the flyby enables ultraviolet measurements of the magnetotail - a region where many of these species are removed from the system. This region is not routinely accessible from the orbital trajectory.

What the Future Holds

Space exploration is a challenge, but a challenge the MESSENGER spacecraft is meeting. With each Mercury flyby, MESSENGER will provide new insights and whet our appetite for more information, until the spacecraft finally enters orbit about Mercury in March 2011. Such is the adventure that awaits us.



The Spacecraft

After Mariner 10's visits to Mercury, the space science and engineering communities yearned for a longer and more detailed look at the innermost planet – but that closer look, ideally from orbit, presented formidable technical obstacles. A Mercury orbiter would have to be tough, with enough protection to withstand searing sunlight and roasting heat bouncing back from the planet below. The spacecraft would need to be lightweight, since most of its mass would be fuel to fire its rockets to slow the spacecraft down enough to be captured by Mercury's gravity. And the probe would have to be sufficiently compact to be launched on a conventional and cost-effective rocket.

Designed and built by the Johns Hopkins University Applied Physics Laboratory – with contributions from research institutions and companies around the world – the MESSENGER spacecraft tackles each of these challenges. A ceramic-fabric sunshade, heat radiators, and a mission design that limits time over the planet's hottest regions protect MESSENGER without expensive and impractical cooling systems. The spacecraft's graphite composite structure – strong, lightweight, and heat tolerant – is integrated with a low-mass propulsion system that efficiently stores and distributes the approximately 600 kilograms (about 1,320 pounds) of propellant that accounts for 54 % of MESSENGER's total launch weight.

To fit behind the 2.5-meter by 2-meter (roughly 8-foot by 6-foot) sunshade, MESSENGER's wiring, electronics, systems, and instruments are packed into a small frame that could fit inside a large sport utility vehicle. And the entire spacecraft is light enough to launch on a Delta II 7925-H ("heavy") rocket, the largest launch vehicle allowed under NASA's Discovery Program of lower-cost space science missions.

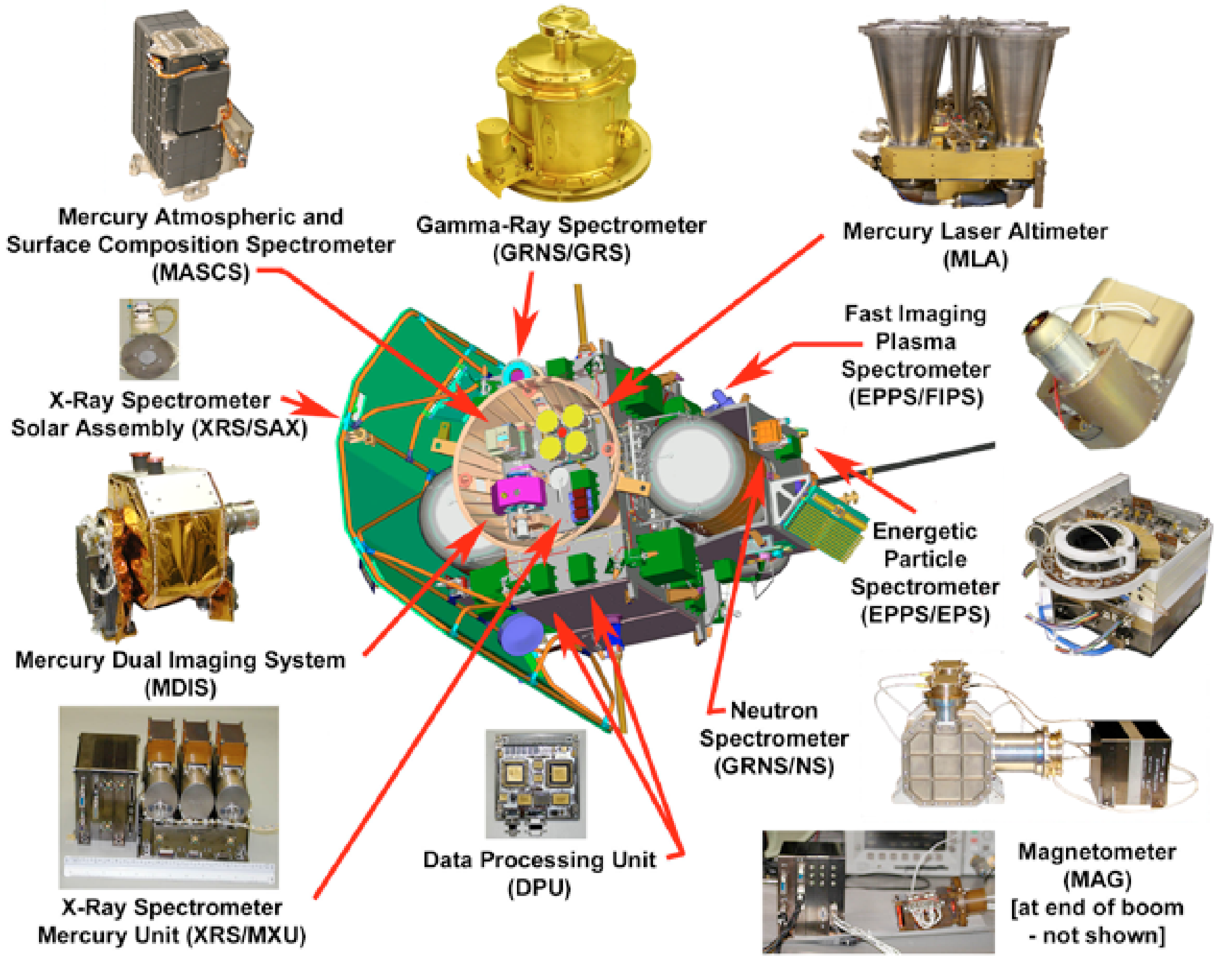
MESSENGER spacecraft during integration and testing. The sunshade is visible on the left with the spacecraft undergoing testing in thermal-vacuum conditions at NASA's Goddard Space Flight Center. On the right, the solar panels and Magnetometer boom are in their position for flight during work at APL.

Science Payload

MESSENGER carries seven scientific instruments and a radio science experiment to accomplish an ambitious objective: return the first data from Mercury orbit. The miniaturized payload – designed to work in the extreme environment near the Sun – will image all of Mercury for the first time, as well as gather data on the composition and structure of Mercury's crust, its geologic history, the nature of its active magnetosphere and thin atmosphere, and the makeup of its core and the materials near its poles.

The instruments include the Mercury Dual Imaging System (MDIS), the Gamma-Ray and Neutron Spectrometer (GRNS), the X-Ray Spectrometer (XRS), the Magnetometer (MAG), the Mercury Laser Altimeter (MLA), the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), and the Energetic Particle and Plasma Spectrometer (EPPS). The instruments communicate to the spacecraft through fully redundant Data Processing Units (DPUs).

Spacecraft Instruments



The process of selecting the scientific instrumentation for a mission is typically a balance between answering as many science questions as possible and fitting within the available mission resources for mass, power, mechanical accommodation, schedule, and cost. In the case of MESSENGER, the mass and mechanical accommodation issues were very significant constraints. Payload mass was limited to 50 kilograms (110 pounds) because of the propellant mass needed for orbit insertion. The instrument mechanical accommodation was difficult because of the unique thermal constraints faced during the mission; instruments had to be mounted where Mercury would be in view but the Sun would not, and they had to be maintained within an acceptable temperature range in a very harsh environment. Instrument details follow. In each case the mass includes mounting hardware and thermal control components, and the power is the nominal average power consumption per orbit; actual values vary with instrument operational mode.

Mercury Dual Imaging System

Mass: 8.0 kilograms (17.6 pounds)

Power: 7.6 watts
Development: Johns Hopkins University Applied Physics Laboratory

The multi-spectral **MDIS** has wide- and narrow-angle cameras (the "WAC" and "NAC," respectively) – both based on charge-coupled devices (CCDs), similar to those found in digital cameras – to map the rugged landforms and spectral variations on Mercury's surface in monochrome, color, and stereo. The imager pivots, giving it the ability to capture images from a wide area without having to re-point the spacecraft and allowing it to follow the stars and other optical navigation guides.

The wide-angle camera has a 10.5° by 10.5° field of view and can observe Mercury through 11 different filters and monochrome across the wavelength range 395 to 1,040 nanometers (visible and near-infrared light). Multi-spectral imaging will help scientists investigate the diversity of rock types that form Mercury's surface. The narrow-angle camera can take black-and-white images at high resolution through its 1.5° by 1.5° field of view, allowing extremely detailed analysis of features as small as 18 meters (about 60 feet) across.

Gamma-Ray and Neutron Spectrometer

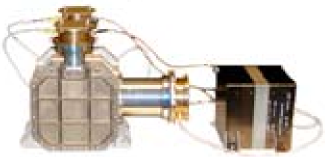
GRNS packages separate gamma-ray and neutron spectrometers to collect complementary data on elements that form Mercury's crust.

Gamma-Ray Spectrometer

Mass: 9.2 kilograms (20.3 pounds)
Power: 6.6 watts
Development: Johns Hopkins University Applied Physics Laboratory, Patriot Engineering, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory

GRS measures gamma rays emitted by the nuclei of atoms on Mercury's surface that are struck by cosmic rays. Each element has a signature emission, and the instrument will look for geologically important elements such as hydrogen, magnesium, silicon, oxygen, iron, titanium, sodium, and calcium. It may also detect naturally radioactive elements such as potassium, thorium, and uranium.

Neutron Spectrometer



Mass: 3.9 kilograms (8.6 pounds)
Power: 6.0 watts
Development: Johns Hopkins University Applied Physics Laboratory, Patriot Engineering, Los Alamos National Laboratory

NS maps variations in the fast, thermal, and epithermal neutrons Mercury's surface emits when struck by cosmic rays. "Fast" neutrons shoot directly into space; others collide with neighboring atoms in the crust before escaping. If a neutron collides with a light atom (like hydrogen), it will lose energy and be detected as a slow (or thermal) neutron. Scientists can look at the ratio of thermal to epithermal (slightly faster) neutrons across Mercury's surface to estimate the amount of hydrogen – possibly locked up in water molecules – and other elements.

X-Ray Spectrometer

Mass: 3.4 kilograms (7.5 pounds)
Power: 6.9 watts
Development: Johns Hopkins University Applied Physics Laboratory

XRS maps the elements in the top millimeter of Mercury's crust using three gas-filled detectors (MXU) pointing at the planet, one silicon solid-state detector pointing at the Sun (SAX), and the associated electronics (MEX). The planet-pointing detectors measure fluorescence, the X-ray emissions coming from Mercury's surface after solar X-rays hit the planet. The Sun-pointing detector tracks the X-rays bombarding the planet

XRS detects emissions from elements in the 1-10 kiloelectron-volt (keV) range – specifically, magnesium, aluminum, silicon, sulfur, calcium, titanium, and iron. Two detectors have thin absorption filters that help distinguish among the lower-energy X-ray lines of magnesium, aluminum, and silicon.

Beryllium-copper honeycomb collimators give XRS a 12° field of view, which is narrow enough to eliminate X-rays from the star background even when MESSENGER is at its farthest orbital distance from Mercury. The small, thermally protected, solar-flux monitor is mounted on MESSENGER's sunshade.

Hot Space, Cool Instrument

To help it measure surface gamma rays from long distances, MESSENGER uses the most sensitive detector available – a high-purity germanium semiconductor crystal. But while MESSENGER moves through one of the solar system's hottest environments, the crystal must operate at cryogenic temperatures. Instrument designers addressed this challenge by suspending the detector on thin Kevlar strings inside a high-tech thermos bottle, with a small, powerful refrigerator (called a cryocooler) that keeps temperatures at a frosty –183° Celsius, or about –300° Fahrenheit.

Magnetometer

Mass (including boom): 4.4 kilograms (9.7 pounds)
Power: 4.2 watts
Development: NASA Goddard Space Flight Center, Greenbelt, Md., and Johns Hopkins University Applied Physics Laboratory

A three-axis, ring-core fluxgate detector, **MAG** characterizes Mercury's magnetic field in detail, helping scientists determine the field's exact strength and how it varies with position and altitude. Obtaining this information is a critical step toward determining the source of Mercury's magnetic field.

The MAG sensor is mounted on a 3.6-meter (nearly 12-foot long) boom that keeps it away from the spacecraft's own magnetic field. The sensor also has its own sunshade to protect it from the Sun when the spacecraft is tilted to allow for viewing by the other instruments. While in orbit at Mercury the instrument will collect magnetic field samples at 50-millisecond to one-second intervals; the rapid sampling will take place near Mercury's magnetosphere boundaries.

Mercury Laser Altimeter

Mass: 7.4 kilograms (16.3 pounds)
Peak Power: 16.4 watts
Development: NASA Goddard Space Flight Center

MLA maps Mercury's landforms and other surface characteristics using an infrared laser transmitter and a receiver that measures the round-trip time of individual laser pulses. The data will also be used to track the planet's slight, forced libration – a wobble about its spin axis – which will tell researchers about the state of Mercury's core.

MLA data combined with Radio Science Doppler ranging will be used to map the planet's gravitational field. MLA can view the planet from up to 1,000 kilometers (620 miles) away with an accuracy of 30 centimeters (about one foot). The laser's transmitter, operating at a wavelength of 1,064 nanometers, will deliver eight pulses per second. The receiver consists of four sapphire lenses, a photon-counting detector, a time-interval unit, and processing electronics.

Mercury Atmospheric and Surface Composition Spectrometer

Mass: 3.1 kilograms (6.8 pounds)
Peak Power: 6.7 watts
Development: Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder

Combining an ultraviolet spectrometer and infrared spectrograph, **MASCS** will measure the abundance of atmospheric gases around Mercury and detect minerals in its surface materials.

The *Ultraviolet and Visible Spectrometer* (UVVS) will determine the composition and structure of Mercury's exosphere – the extremely low-density atmosphere – and study its neutral gas emissions. It will also search for and measure ionized atmospheric species. Together these measurements will help researchers understand the processes that generate and maintain the atmosphere, the connection between surface and atmospheric composition, the dynamics of volatile materials on and near Mercury, and the nature of the radar-reflective materials near the planet's poles. The instrument has 25-kilometer resolution at the planet's limb.

Perched atop the ultraviolet spectrometer, the *Visible and Infrared Spectrograph* (VIRS) will measure the reflected visible and near-infrared light at wavelengths diagnostic of iron and titanium-bearing silicate materials on the surface, such as pyroxene, olivine, and ilmenite. The sensor's best resolution is 3 kilometers at Mercury's surface.

Energetic Particle and Plasma Spectrometer

EPS on left and FIPS on right

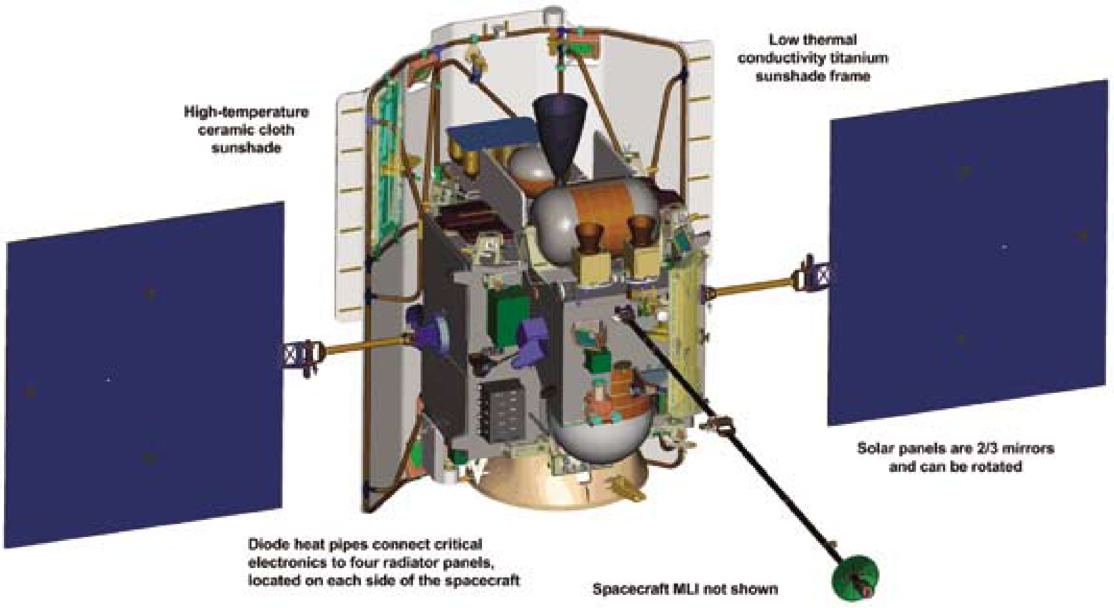
Mass: 3.1 kilograms (6.8 pounds)
Peak Power: 7.8 watts
Development:, Johns Hopkins University Applied Physics Laboratory and University of Michigan, Ann Arbor

EPPS will measure the mix and characteristics of charged particles in and around Mercury's magnetosphere using an *Energetic Particle Spectrometer (EPS)* and a *Fast Imaging Plasma Spectrometer (FIPS)*. Both are equipped with time-of-flight and energy-measurement technologies to determine particle velocities and elemental species.

From its vantage point near the top deck of the spacecraft, EPS will observe ions and electrons accelerated in the magnetosphere. EPS has a 160° by 12° field of view for measuring the energy spectra and pitch-angle distribution of these ions and electrons. Mounted on the side of the spacecraft, FIPS will observe low-energy ions coming from Mercury's surface and sparse atmosphere, ionized atoms picked up by the solar wind, and other solar-wind components. FIPS provides nearly full hemispheric coverage.

Radio Science observations – gathered by tracking the spacecraft through its communications system – will precisely measure MESSENGER's speed and distance from Earth. From this information, scientists and engineers will watch for changes in MESSENGER's movements at Mercury to measure the planet's gravity field, and to support the laser altimeter investigation to determine the size and condition of Mercury's core. NASA's Goddard Space Flight Center leads the Radio Science investigation.

Spacecraft Systems and Components



MESSENGER spacecraft in flight configuration, rear view

Thermal Design

While orbiting Mercury, MESSENGER will "feel" significantly hotter than spacecraft that orbit Earth. This is because Mercury's elongated orbit swings the planet to within 46 million kilometers (29 million miles) of the Sun, or about two-thirds closer to the Sun than Earth. As a result, the Sun shines up to 11 times brighter at Mercury than we see from our own planet.

MESSENGER's first line of thermal defense is a heat-resistant and highly reflective sunshade, fixed on a titanium frame to the front of the spacecraft. Measuring about 2.5 meters (8 feet) tall and 2 meters (6 feet) across, the thin shade has front and back layers of Nextel ceramic cloth – the same material that protects sections of the space shuttle – surrounding several inner layers of Kapton plastic insulation. While temperatures on the front of the shade could reach 370° C (about 700° F) when Mercury is closest to the Sun, behind it the spacecraft will operate at room temperature, around 20° C (about 70° F). Multilayered insulation covers most of the spacecraft.

Radiators and diode ("one-way") heat pipes are installed to carry heat away from the spacecraft body, and the science orbit is designed to limit MESSENGER's exposure to heat re-radiating from the surface of Mercury. (MESSENGER will only spend about 25 minutes of each 12-hour orbit crossing Mercury's broiling surface at low altitude.) The combination of the sunshade, thermal blanketing, and heat-radiation system allows the spacecraft to operate without special high-temperature electronics.

Power

Two single-sided solar panels are the spacecraft's main source of electric power. To run MESSENGER's systems and charge its 23-ampere-hour nickel-hydrogen battery, the panels, each about 1.5 meters (5 feet) by 1.65 meters (5.5 feet), will support between 385 and 485 watts of spacecraft load power during the cruise phase and 640 watts during the orbit at Mercury. The panels could produce more than two kilowatts of power near Mercury, but to prevent stress on MESSENGER's electronics, onboard power processors take in only what the spacecraft actually needs.

The custom-developed panels are two-thirds mirrors (called optical solar reflectors) and one-third triple-junction solar cells, which convert 28 percent of the sunlight hitting them into electricity. Each panel has two rows of mirrors for every row of cells; the small mirrors reflect the Sun's energy and keep the panel cooler. The panels also rotate, so MESSENGER's flight computer will tilt the panels away from the Sun, positioning them to get the required power while maintaining a normal surface operating temperature of about 150° Celsius, or about 300° Fahrenheit.

Propulsion

MESSENGER's dual-mode propulsion system includes a 660-newton (150-pound) bipropellant thruster for large maneuvers and 16 hydrazine-propellant thrusters for smaller trajectory adjustments and attitude control. The Large Velocity Adjust (LVA) thruster requires a combination of hydrazine fuel and an oxidizer, nitrogen tetroxide. Fuel and oxidizer are stored in custom-designed, lightweight titanium tanks integrated into the spacecraft's composite frame. Helium pressurizes the system and pushes the fuel and oxidizer through to the engines.

At launch the spacecraft carried just under 600 kilograms (about 1,320 pounds) of propellant, and it will use nearly 30 percent of it during the maneuver that inserts the spacecraft into orbit about Mercury. The small hydrazine thrusters play several important roles: four 22-newton (5-pound) thrusters are used for small course corrections and help steady MESSENGER during large engine burns. The dozen 4.4-newton (1-pound) thrusters are also used for small course corrections and serve as a backup for the reaction wheels that maintain the spacecraft's orientation during normal cruise and orbital operations.

Communications

MESSENGER's X-band coherent communications system includes two high-gain, electronically steered, phased array antennas – the first ever used on a deep-space mission; two medium-gain fanbeam antennas; and four low-gain antennas. The circularly polarized phased arrays – developed by APL and located with the fanbeam antennas on the front and back of the spacecraft – are the main link for sending science data to Earth. For better reliability the antennas are fixed; they "point" electronically across a 45° field without moving parts, and during normal operations at least one of the two antennas points at Earth.

High-gain antennas send radio signals through a narrower, more concentrated beam than low-gain antennas and are used primarily to send larger amounts of data over the same distance as a low-gain antenna. The fanbeam and low-gain antennas, also located on MESSENGER's front and back sides, are used for lower-rate transmissions such as operating commands, status data, or emergency communications. MESSENGER's downlink rate ranges from 9.9 bits per second to 104 kilobits per second; operators can send commands at 7.8 to 500 bits per second. Transmission rates vary according to spacecraft distance and ground-station antenna size.

Command and Data Handling

MESSENGER's "brain" is its Integrated Electronics Module (IEM), a space- and weight-saving device that combines the spacecraft's core avionics into a single box. The spacecraft carries a pair of identical IEMs for backup purposes; both house a 25-megahertz (MHz) main processor and 10-MHz fault protection processor. All four are radiation-hardened RAD6000 processors, based on predecessors of the PowerPC chip found in some models of home computers. The computers, slow by current home-computer standards, are state of the art for the radiation tolerance required on the MESSENGER mission.

Programmed to monitor the condition of MESSENGER's key systems, both fault protection processors are turned on at all times and protect the spacecraft by turning off components and/or switching to backup components when necessary. The main processor runs the Command and Data Handling software for data transfer and file storage, as well as the Guidance and Control software used to navigate and point the spacecraft. Each IEM also includes a solid-state data recorder, power converters, and the interfaces between the processors and MESSENGER's instruments and systems.

Intricate flight software guides MESSENGER's Command and Data Handling system. MESSENGER receives operating commands from Earth and can perform them in real time or store them for later execution. Some of MESSENGER's frequent, critical operations (such as propulsive maneuvers) are programmed into the flight computer's memory and timed to run automatically.

For data, MESSENGER carries two solid-state recorders (one backup) able to store up to 1 gigabyte each. Its main processor collects, compresses, and stores images and other data from MESSENGER's instruments onto the recorder; the software sorts the data into files similar to how files are stored on a PC. The main processor selects the files with highest priority to transmit to Earth, or mission operators can download data files in any order the team chooses.

Antenna signal strength (and downlink rate) varies with spacecraft-Earth distance and ground-station antenna size. While orbiting Mercury MESSENGER will store most of its data when it's farther from Earth, typically sending only information on its condition and the highest-priority images and measurements during regular eight-hour contacts through NASA's Deep Space Network. The spacecraft will send most of the recorded data when Mercury's path around the Sun brings it closer to Earth.

Guidance and Control

MESSENGER is well protected against the heat, but it must always know its orientation relative to Mercury, Earth, and the Sun and be "smart" enough to keep its sunshade pointed at the Sun. Attitude determination – knowing in which direction MESSENGER is facing – is performed using star-tracking cameras, digital Sun sensors, and an Inertial Measurement Unit (IMU, which contains gyroscopes and accelerometers). Attitude control for the 3-axis stabilized craft is accomplished using four internal reaction wheels and, when necessary, MESSENGER's small thrusters.

The IMU accurately determines the spacecraft's rotation rate, and MESSENGER tracks its own orientation by checking the location of stars and the Sun. Star-tracking cameras on MESSENGER's top deck store a complete map of the heavens; 10 times a second, one of the cameras takes a wide-angle picture of space, compares the locations of stars to its onboard map, and then calculates the spacecraft's orientation. The Guidance and Control software also automatically rotates the spacecraft and solar panels to the desired Sun-relative orientation, making sure the panels produce sufficient power while maintaining safe temperatures.

Five Sun sensors back up the star trackers, continuously measuring MESSENGER's angle to the Sun. If the flight software detects that the Sun is "moving" out of a designated safe zone it can initiate an automatic turn to ensure that the shade faces the Sun. Ground controllers can then analyze the situation while the spacecraft turns its antennas to Earth and awaits instructions – an operating condition known as "safe" mode.

Hardware Suppliers

Spacecraft Hardware Suppliers

Antenna Waveguide: Continental Microwave, Exeter, N.H.
Battery (with APL): Eagle Picher Technologies, Joplin, Mo.
Heat Pipes: ATK, Beltsville, Md.
Inertial Measurement Unit: Northrop Grumman, Woodland Hills, Calif.
Integrated Electronics Module (with APL): BAE systems, Manassas, Va.
Launch Vehicle: Boeing, Huntington Beach, Calif.
Precision Oscillator: Datum Timing Test and Measurement, Beverly, Mass.
Propulsion: Aerojet, Sacramento, Calif.
Reaction Wheels: Teldix GmbH, Heidelberg, Germany.
Semiconductors: TriQuint, Dallas, Tex.
Solar Array Drives: Moog, Inc., East Aurora, N.Y.
Solar Arrays: Northrop Grumman Space Technology, Redondo Beach, Calif.
Solid-State Power Amplifier Converters: EMS Technologies, Montreal, Canada.
Star Trackers: Galileo Avionica, Florence, Italy.
Structure: ATK Composite Optics, Inc., San Diego, Calif.
Sun Sensors: Adcole Corporation, Marlborough, Mass.
Transponder: General Dynamics, Scottsdale, Ariz.

Instrument Hardware Suppliers

MDIS: Integrator: APL, Laurel, Md.
SSG, Inc. (NAC telescope), Wilmington, Mass.
Atmel (CCD), San Jose, Calif.
CDA Intercorp (filter wheel motor for WAC), Deerfield, Fl.
Starsys Research (pivot motor), Boulder, Colo.
Optimax (WAC lenses), Chicago, Ill.
Northrop Grumman Poly Scientific (twist capsule), Blacksburg, Va.
Optical Coating Laboratory, Inc. (heat filters), Santa Rosa, Calif.

GRNS: Integrator: APL, Laurel, Md.
Ricor (cooler), Israel.
Patriot Engineering (design, analysis, and subassembly of sensors), Chagrin Falls, Oh.
Hammamatsu Corp. (photomultipliers), Japan.
Lawrence Berkeley National Laboratory (GRS), Berkeley, Calif.
Lawrence Livermore National Laboratory (GRS), Livermore, Calif.
Space Science Laboratory, University of California, Berkeley, (GRS).

XRS: Integrator: APL, Laurel, Md.
Amptek (components), Bedford, Mass.
Metorex (X-ray sensor tubes), Espoo, Finland.

MAG: Integrator and digital electronics: APL, Laurel, Md.
Goddard Space Flight Center (sensor and analog electronics), Greenbelt, Md.

MLA: Integrator: Goddard Space Flight Center, Greenbelt, Md.

MASCS: Integrator: LASP, University of Colorado, Boulder.

EPPS: Integrator, common electronics, and EPS subassembly: APL, Laurel, Md.
University of Michigan (FIPS subassembly), Ann Arbor, Mich.
Amptek (components), Bedford, Mass.
Luxel (microchannel plate), Friday Harbor, Wash.
Micron Semiconductor (solid-state detectors), UK.

The MESSENGER Science Team

MESSENGER's Science Team consists of experts in all fields of planetary science, brought together by their ability to complete the science investigations conducted by MESSENGER. The team is divided into four disciplinary groups: (1) Geochemistry, (2) Geology, (3) Geophysics, and (4) Atmosphere and Magnetosphere, with each team member given responsibility for implementation of a particular part of the mission's science plan.

Principal Investigator: Sean C. Solomon, Director of the Department of Terrestrial Magnetism at the Carnegie Institution of Washington
Project Scientist: Ralph L. McNutt, Jr., Johns Hopkins University Applied Physics Laboratory (JHUAPL)
Deputy Project Scientists: Brian J. Anderson and Deborah L. Domingue, JHUAPL

Science Team Members:

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University of Colorado

Mehdi Benna
NASA Goddard Space Flight Center

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JHUAPL

William V. Boynton
University of Arizona

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Southwest Research Institute

Andrew F. Cheng
JHUAPL

Deborah L. Domingue
JHUAPL

Larry G. Evans
Computer Sciences Corporation and NASA Goddard Space Flight Center

William C. Feldman
Planetary Science Institute

Robert Gaskell
Planetary Science Institute

Jeffrey Gillis-Davis
University of Hawaii

George Gloeckler
University of Michigan and University of Maryland

Robert E. Gold
JHUAPL

Steven A. Hauck, II
Case Western Reserve University

James W. Head III
Brown University

Jörn Helbert
Institute for Planetary Research, Deutsches Zentrum für Luft- und Raumfahrt

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Rosemary Killen
University of Maryland

Stamatios M. Krimigis
JHUAPL and the Academy of Athens

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Los Alamos National Laboratory

Jean-Luc Margot
Cornell University

William McClintock
University of Colorado

Tim McCoy
Smithsonian Institution National Museum of Natural History

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JHUAPL

Scott L. Murchie
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Carnegie Institution of Washington

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Southwest Research Institute

Michael E. Purucker
Raytheon at Planetary Geodynamics Lab, NASA Goddard Space Flight Center

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Arizona State University

David Schriver
University of California, Los Angeles

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NASA Goddard Space Flight Center

Ann L. Sprague
University of Arizona

David E. Smith
NASA Goddard Space Flight Center

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The Catholic University of America

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Faith Vilas
MMT Observatory

Thomas R. Watters
Smithsonian Institution National Air and Space Museum

Maria T. Zuber
Massachusetts Institute of Technology

Program/Project Management

Sean C. Solomon of the Carnegie Institution of Washington (CIW) leads the MESSENGER mission as principal investigator. The Johns Hopkins University Applied Physics Laboratory (APL), Laurel, Md., manages the MESSENGER mission for NASA's Science Mission Directorate, Washington.

At NASA Headquarters, Alan Stern is the associate administrator for NASA's Science Mission Directorate. James Green is the director of that directorate's Planetary Science Division. Anthony Carro is the MESSENGER program executive and Marilyn Lindstrom is the MESSENGER program scientist. Paul Gilbert is the Discovery Program manager, and Allen Bacskay is the Discovery Mission manager for MESSENGER; the NASA Discovery Program is managed out of the Marshall Space Flight Center.

At APL, Peter Bedini is the project manager, Ralph L. McNutt, Jr., is MESSENGER project scientist, Eric Finnegan is mission systems engineer, and Andy Calloway is mission operations manager.

NASA Discovery Program

MESSENGER is the seventh mission in NASA's Discovery Program of lower cost, highly focused planetary science investigations. Created in 1992, Discovery challenges teams of scientists and engineers to find innovative and imaginative ways to uncover the mysteries of the solar system within limited cost-capped budgets and schedules.

Other Discovery Missions

NEAR (Near Earth Asteroid Rendezvous) marked the Discovery Program's first launch, in February 1996. The NEAR Shoemaker spacecraft became the first to orbit an asteroid when it reached 433 Eros in February 2000. After collecting 10 times the data initially expected during a year around Eros, in February 2001, NEAR Shoemaker became the first spacecraft to actually land on an asteroid and collect data from its surface.

Mars Pathfinder launched December 1996 and landed on Mars in July 1997. The mission demonstrated several tools and techniques for future Mars missions – such as entering, descending, and landing with airbags to deliver a robotic rover – while captivating the world with color pictures from the red planet.

Lunar Prospector orbited Earth's Moon for 18 months after launching in January 1998. The mission's data enabled scientists to create detailed maps of the gravity, magnetic properties, and chemical makeup of the Moon's entire surface.

Stardust, launched in February 1999, collected samples of comet dust and provided the closest look yet at a comet nucleus when it sailed through the coma of Wild 2 in January 2004. It returned the cometary dust to Earth in January 2006.

Genesis, launched in August 2001, collected solar wind particles and returned them to Earth in September 2004. The samples are improving our understanding of the isotopic composition of the Sun, information that will help to identify what the young solar system was like.

CONTOUR (Comet Nucleus Tour) was designed to fly past and study at least two very different comets as they visited the inner solar system. The spacecraft was lost six weeks after launch, during a critical rocket-firing maneuver in August 2002 to boost it from Earth's orbit onto a comet-chasing path around the Sun.

Deep Impact, launched in January 2005, was the first experiment to probe beneath the surface of a comet, attempting to reveal never before seen materials that would provide clues to the internal composition and structure of a comet. A variety of instruments, both onboard the spacecraft and at ground-based and space-based observatories around the world, observed the impact with the comet and examined the resulting debris and interior material.

Dawn, launched in September 2007 toward Vesta and Ceres, two of the largest main-belt asteroids in our solar system, and will provide key data on asteroid properties by orbiting and observing these minor planets.

Kepler, planned for a February 2009 launch, will monitor 100,000 stars similar to our Sun for four years, using new technology to search the galaxy for Earth-size (or smaller) planets for the first time.

The **Gravity Recovery and Interior Laboratory**, or GRAIL, mission, scheduled to launch in 2011, will fly twin spacecraft in tandem orbits around the Moon for several months to measure its gravity field in unprecedented detail. The mission also will answer longstanding questions about Earth's Moon and provide scientists a better understanding of how Earth and other rocky planets in the solar system formed.

Discovery also includes Missions of Opportunity – not complete Discovery missions, but pieces of a larger NASA or non-NASA missions or creative reuses of spacecraft that have completed their prime missions. Those selected to date for flight include:

- The **ASPERA-3** (Analyzer of Space Plasma and Energetic Atoms) instrument is studying the interaction between the solar wind and the Martian atmosphere from the European Space Agency's Mars Express spacecraft, which began orbiting Mars in December 2003.

- The **M3** (Moon Mineralogy Mapper), pronounced M-cube, is one of eleven instruments that will fly on board Chandrayaan-1, scheduled to launch in March 2008. Chandrayaan-1, India's first deep space mission, is a project of the Indian Space Research Organisation (ISRO). The goals of the mission include expanding scientific knowledge of the Moon, upgrading India's technological capability, and providing challenging opportunities for planetary research for the younger generation.

- The **EPOXI** mission combines two science investigations – the Extrasolar Planet Observation and Characterization (EPOCh) and the Deep Impact Extended Investigation (DIXI). Both investigations will be performed using the Deep Impact spacecraft, which finished its prime mission in 2005. EPOCh will use the Deep Impact spacecraft to observe several nearby bright stars for transits by orbiting planets, and DIXI involves a flyby of comet Hartley 2 in October 2010.

- **NExT** (New Exploration of Tempel 1) will reuse NASA's Stardust spacecraft to revisit comet Tempel 1, the cometary target of Deep Impact. This investigation will provide the first look at the changes to a comet nucleus produced after its close approach to the Sun. NExT is scheduled to fly by Tempel 1 in February 2011.

For more on the Discovery Program, visit http://discovery.nasa.gov.