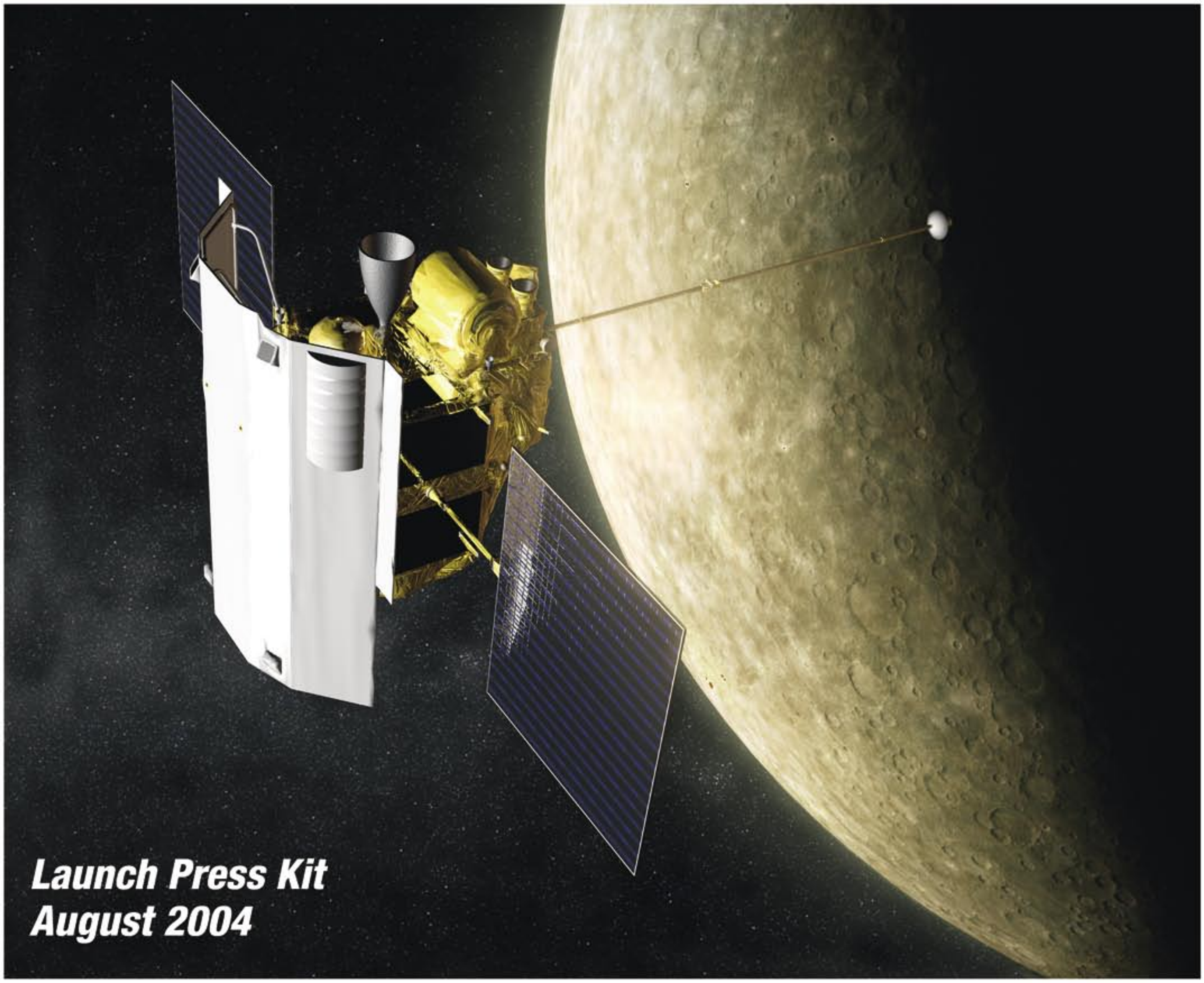
MESSENGER

NASA's Mission to Mercury



Launch Press Kit
August 2004

A NASA Discovery Mission

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General Release

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NASA SENDING A MESSENGER TO MERCURY

NASA's first trip to Mercury in 30 years – and the closest look ever at the innermost planet – starts in August with the predawn launch of the MESSENGER spacecraft from Cape Canaveral Air Force Station, Fla.

MESSENGER will conduct an in-depth study of the Sun's closest neighbor, the least explored of the terrestrial ("rocky") planets that also include Venus, Earth and Mars. After a scheduled 2:16 a.m. (EDT) liftoff aboard a Delta II launch vehicle on Aug. 2 – the first day of a 13-day launch period – MESSENGER's voyage includes three flybys of Mercury in 2008 and 2009 and a yearlong orbit of the planet starting in March 2011.

"Our missions to Mars and Venus have produced exciting data and new theories about the processes that formed the inner planets," says Orlando Figueroa, director of the Solar System Exploration Division at NASA Headquarters, Washington. "Yet Mercury still stands out as a planet with a fascinating story to tell. MESSENGER should complete the detailed exploration of the inner solar system – our planetary backyard – and help us to understand the forces that shaped planets like our own."

MESSENGER (short for MErcury Surface, Space ENvironment, GEochemistry, and Ranging) is only the second spacecraft to set sights on Mercury; Mariner 10 sailed past it three times in 1974 and 1975 and gathered detailed data on less than half the surface. Carrying seven scientific instruments on its compact and durable composite frame, MESSENGER will provide the first images of the entire planet. The mission will also collect detailed information on the composition and structure of Mercury's crust, its geologic history, the nature of its thin atmosphere and active magnetosphere, and the makeup of its core and polar materials.

MESSENGER's science team will shape its investigation around several questions, including: Why is Mercury – the densest planet in the solar system – mostly made of iron? Why is it the only inner planet besides Earth with a global magnetic field? How can the planet closest to the Sun, with daytime temperatures near 840 degrees Fahrenheit, have what appears to be ice in its polar craters?

"For nearly 30 years we've had questions that couldn't be answered until technology and mission designs caught up with our desire to go back to Mercury," says Dr. Sean C. Solomon, MESSENGER principal investigator, from the Carnegie Institution of Washington. "Now we are ready. The answers to these questions will not only tell us more about Mercury, but illuminate processes that affect all the terrestrial planets."

Mercury's proximity to the Sun makes it both a fascinating subject and an unprecedented mission design challenge. The Sun can be up to 11 times brighter than what we see on Earth and surface temperatures at Mercury's equator can reach 450 degrees Celsius (about 840 degrees Fahrenheit), but MESSENGER will operate at room temperature behind a sunshade of heat-resistant ceramic fabric. The 1.2-ton spacecraft also features a heat-radiation system and will pass only briefly over Mercury's hottest regions, limiting exposure to the intense heat bouncing back from the broiling surface.

"We're doing something no one has ever tried before," says MESSENGER Project Manager David G. Grant, of the Johns Hopkins University Applied Physics Laboratory (APL), Laurel, Md. "After launch and a long trip through the inner solar system, we still face the risky and difficult job of orbiting the planet next to the Sun. The team is confident that the spacecraft they designed, built and tested is ready for this journey and its mission to Mercury."

On a 4.9-billion mile (7.9-billion kilometer) journey that includes 15 loops around the Sun, the solar-powered MESSENGER will fly past Earth once, Venus twice and Mercury three times before easing into orbit around its target planet. The Earth flyby, a year after launch, and the Venus flybys, in October 2006 and June 2007, use the pull of the planets' gravity to guide MESSENGER toward Mercury's orbit. The Mercury flybys in January 2008, October 2008 and September 2009 fine-tune and slow MESSENGER's track while allowing the spacecraft to gather data critical to planning the mission's orbit phase.

The MESSENGER project is the seventh in NASA's Discovery Program of lower-cost, scientifically focused space missions. Solomon leads the mission as principal investigator; APL manages the mission for NASA's Office of Space Science and designed, built and will operate the MESSENGER spacecraft. MESSENGER's science instruments were built by APL; NASA Goddard Space Flight Center, Greenbelt, Md.; University of Michigan, Ann Arbor; and University of Colorado, Boulder. GenCorp Aerojet, Sacramento, Calif., and Composite Optics Inc., San Diego, provided MESSENGER's propulsion system and composite structure, respectively.

The MESSENGER science team draws expertise from APL; Brown University, Providence, R.I.; Carnegie Institution of Washington; Goddard Space Flight Center; Los Alamos National Laboratory, N.M.; Massachusetts Institute of Technology, Cambridge; Northwestern University, Evanston, Ill.; Southwest Research Institute, Boulder, Colo.; University of Arizona, Tucson; University of California, Santa Barbara; University of Colorado, Boulder; University of Michigan, Ann Arbor; and Washington University, St. Louis.

Additional information about MESSENGER is available on the Web at:
http://messenger.jhuapl.edu

Media Services Information

NASA Television

NASA Television is broadcast on satellite AMC-2, transponder 9C, C-Band, located at 85 degrees West longitude. The frequency is 3880.0 MHz; polarization is vertical and audio monaural at 6.8 MHz. The schedule of television transmissions for MESSENGER will be available from NASA Headquarters and the NASA TV Web site at www.nasa.gov/multimedia/nasatv/index.html.

Briefings and Television Coverage

NASA plans to broadcast the prelaunch media briefings and the launch live on NASA TV. Check the NASA TV schedule for updated dates and times of mission events. Events carried live on NASA TV will also be available through links on the MESSENGER Web site, http://messenger.jhuapl.edu.

News and Status Reports

NASA and the MESSENGER team will issue periodic status reports on mission activities and make them available online at http://messenger.jhuapl.edu. Recorded status reports will be available three days before launch time at (321) 867-2525; launch-related information will also be available through the NASA Kennedy Space Center newsroom at (321) 867-2468.

The Kennedy Space Center will release a Note to Editors approximately 10 days before launch with full details of press accreditation, the prelaunch press conference and mission science briefing, special press opportunities, launch day press logistics, and NASA TV and Web coverage.

Audio

NASA TV audio coverage of the launch will be available by calling (321) 867-1220, -1240, -1260 or -7135, and on amateur radio frequency 146.940 MHz.

Launch Media Credentialing

News media representatives who would like to cover the launch in person must be accredited through the Kennedy Space Center newsroom. Journalists may call (321) 867-2468 for more information.

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 launch information and news is also available at http://www.ksc.nasa.gov/elvnew/messenger.

Information on the NASA Discovery Program is available at http://discovery.nasa.gov.

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; front-mounted ceramic-fabric sunshade is 2.5 meters tall and 2 meters across (8 feet by 6 feet); two side-mounted solar panel “wings” extend about six meters (20 feet) from end to end across the spacecraft

Launch weight: Approximately 1,100 kilograms (2,424 pounds); includes about 600 kilograms (1,323 pounds) of propellant and 500 kilograms (1,101 pounds) “dry” spacecraft and instruments

Power: Solar panels; nickel-hydrogen battery

Propulsion: One bipropellant (hydrazine and nitrogen tetroxide) thruster for large maneuvers; 16 hydrazine-fueled 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/ surface composition spectrometer; laser altimeter; magnetometer; radio science experiment

Mission

Launch vehicle: Delta II, Model 7925-H (“heavy” lift capability with nine solid booster rockets)

Launch period: August 2-August 14, 2004, from Cape Canaveral Air Force Station, Fla. A 12-second launch opportunity is available each day

Spacecraft separation (for August 2): 56 minutes, 43 seconds after launch

Expected Acquisition of Signal (for August 2): Approximately 65 minutes after launch through the Universal Space Network tracking station in South Point, Hawaii; then about 15 minutes later through the 34-meter Deep Space Network antenna at Goldstone, Calif.

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 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 $427 million (including spacecraft and instrument development, launch vehicle, mission operations and data analysis)

Mercury at a Glance

General

- One of five planets known to ancient astronomers; in mythology Mercury was the fleet-footed messenger of the gods, a fitting name for a planet that moves quickly across the sky
- Closest planet to the Sun; second smallest planet in the solar system (larger only than Pluto)
- Visited by only one spacecraft: NASA's Mariner 10 (1974-75), which examined less than half the surface in detail

Physical Characteristics

- Diameter is 4,878 kilometers (3,031 miles), about one-third the size of Earth and slightly larger than our Moon
- Densest planet in the solar system (when corrected for compression), with density 5.3 times greater than water
- Largest known crater on Mercury's pockmarked surface is the Caloris Basin (1,300 kilometers or 800 miles in diameter), likely created by an ancient asteroid impact
- Surface is a combination of craters, smooth plains and long, winding cliffs
- Possible water ice on the permanently shadowed floors of craters in the polar regions
- Enormous iron core takes up 60 percent of the planet's total mass – twice as much as Earth's

Environment

- Experiences the solar system's largest swing in surface temperatures, from highs above 450 degrees Celsius (840 degrees Fahrenheit) to lows below –212 C (–350 F)
- Only inner planet besides Earth with a global magnetic field, though Mercury's field is about 100 times weaker than Earth's (at the surface)
- Extremely thin atmosphere contains hydrogen, helium, oxygen, sodium, potassium and calcium

Orbit

- Average distance from the Sun is 58 million kilometers (36 million miles), about two-thirds closer to the Sun than the Earth
- Highly elliptical (elongated) orbit, ranging from 46 million kilometers (29 million miles) to 70 million kilometers (43 million miles) from the Sun
- Orbits the Sun once every 88 Earth days; moving at an average speed of 48 kilometers (30 miles) per second, it's the "fastest" planet in the solar system
- Rotates on its axis once every 59 Earth days, but because of its slow rotation and fast speed around the Sun, one solar day (from noon to noon at the same place) lasts 176 Earth days, or two Mercury years
- 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?
The Science of MESSENGER

For a world such a relatively small distance from Earth, Mercury remains a big mystery. The planet is hard to study: Its average distance from the Sun is just 58 million kilometers (36 million miles), or about two-thirds closer than Earth's orbit. Mercury is visible from Earth only for several weeks a year, just after sunset or before sunrise, and astronomers have trouble observing it with ground telescopes through the sunlit turbulence of our atmosphere. Even the Hubble Space Telescope cannot view it because stray sunlight could damage its sensitive electronics. As such, many aspects of what we think we know are enigmas, perhaps unique in the solar system.

Thermal and dynamical obstacles challenge any spacecraft bound for Mercury, since it resides deep in the Sun's gravitational well. So far only NASA's Mariner 10 has visited the planet, flying past it three times in 1974-75 but seeing the same sunlit side on each pass. And Mariner 10 was unable to conduct the sort of global reconnaissance scientists now know is needed to put any planet into context.

We know less about Mercury than any of the other planets except Pluto – but what information we do have shows this extreme, odd member of the inner planet family has an incredible, fascinating story to tell. As the first rock from the Sun it has the shortest year and endures more solar radiation than any planet. It is the smallest and densest of the four rocky (or terrestrial) planets – which also include Venus, Earth and Mars – and its battered surface is perhaps one of the oldest in the solar system. It experiences the largest daily range in temperatures; at its hottest (about 450 degrees Celsius, or 840 degrees Fahrenheit) the surface temperature would melt lead, and during its long nights the cold (dipping toward –212 Celsius, or –350 Fahrenheit) could turn oxygen from a gas to liquid.

The MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission is designed to examine the planet in detail, conducting an in-depth global investigation organized around six key science questions. The answers not only will provide information specifically about Mercury, but offer a clearer, general picture of the origins and comparative evolution of all the terrestrial planets – and perhaps hint at what to look for in planetary systems beyond our own.

Learning how Mercury ended up the densest planet (after correcting for internal pressure) will tell us much about how planets form near their parent star. Discovering how Mercury has sustained a magnetic field while larger bodies either lost theirs (as Mars did) or show no sign of ever having one (like Venus) will help us understand how our own planet generates its protective magnetic field. Documenting the nature of Mercury's thin, tenuous atmosphere and the composition of mysterious radar-reflecting deposits near its poles – thought by many scientists to be water ice – will provide new insight into the volatile materials that exist on and around the inner planets.

Key Science Questions

Question 1: Why is Mercury so dense?

Mercury's enormous iron core distinguishes it from every other planet in our solar system. Each terrestrial planet has a dense, iron-rich core covered by a rocky mantle, but Mercury's core takes up more than 60 percent of its total mass – twice as much as Earth's. Why is this so? Is it related to Mercury's proximity to the Sun?

The planet's iron heart makes it incredibly dense, which results in a surface gravity about the same as Mars – a considerably larger planet. Scientists have several theories that could explain the reason for the large core. One is that as the planets formed from the disk-shaped cloud of gas and dust known as the solar nebula, dense particles (such as metallic iron) condensed and were preferentially retained in the innermost regions near the Sun, forming Mercury. Another possible explanation is that tremendous heat from the Sun vaporized part of the outer rock layer on a young Mercury, leaving it a metal-rich cinder. Yet a third idea is that a giant object – perhaps an asteroid – slammed into Mercury soon after it formed, blasting away much of its early crust and upper mantle.

Finding the answer: The evidence for solving the mystery of Mercury's density lies in its crustal silicate chemistry, and the amounts of certain elements (particularly iron, sodium, calcium and titanium) on the surface will tell much about the planet's evolution. Without geochemical remote-sensing tools, Mariner 10 could not provide any information on the chemical makeup of Mercury's surface. MESSENGER's spectrometers will examine the composition of the rocks on the surface and determine which minerals and elements are present – and which are conspicuously absent. This approach has been profoundly effective for the Moon and Mars.

Question 2: What is Mercury's geologic history?

Mercury has several mysterious landscape features that beg explanation, such as the relatively "young" plains seen as smooth deposits between surfaces that contain the planet's oldest craters. Many scientists believe flowing lava created the plains, but no one knows for sure.

Over time, bombardment from stray comets and asteroids changed Mercury's surface. Without encountering a significant atmosphere to burn up incoming debris, many objects slammed into the planet to form large and small impact craters. The largest impacts, like the one that formed the Texas-sized Caloris Basin, appear to have transformed entire regions of Mercury's surface, similar to ones on the Moon. The ramparts of Caloris span 1,300 kilometers (about 800 miles) and the tallest mountains climb past 3 kilometers (nearly 2 miles). Theory holds that shock waves from the Caloris impact created the area of chaotic terrain on the opposite side of the planet.

Other mysteries include hundreds of superimposed scarps – curving cliffs, typically hundreds of meters high and tens to hundreds of kilometers long. When did they form and in what sequence? It is possible these scarps formed as Mercury's interior cooled, causing the whole planet to shrink and its crust to contract. How much contraction, in turn, caused Mercury's crust to buckle and scarps to form? Similar features form here on Earth as lava flows cool and shrink.

Finding the answer: MESSENGER will shed unprecedented light on the forces that shaped Mercury's surface. Its X-ray, gamma-ray, and visible-infrared spectrometers will measure the major elements and minerals in Mercury's surface rocks. The camera will photograph all of the planet, including the 55 percent that Mariner 10 missed – and at much higher resolution than Mariner 10's images. Nearly all of Mercury will be imaged in stereo to determine topographic variations and landforms across the globe. The laser altimeter will precisely measure the topography of surface features, and these data, when compared with gravity field measurements gathered by tracking MESSENGER's subtle movements in orbit, will help determine the thickness and structure of Mercury's crust.

Question 3: What is the structure of Mercury's core?

The biggest surprise from the Mariner 10 flybys was that Mercury has a global magnetic field, making it the only terrestrial (rocky) planet besides Earth to have one. Mercury's magnetic field is weak – about 100 times weaker than Earth's at the surface – but that it exists at all raises interesting questions about activity deep inside the planet.

Earth's magnetic field is generated by the swirling motions of molten liquid in our planet's outer core. But Mercury is so much smaller than Earth – 4,878 kilometers in diameter vs. Earth's 12,714 kilometers (3,031 miles vs. 7,900 miles) – that its core should have cooled and solidified long ago. Its many long scarps suggest that the planet has contracted and the core has cooled, so how could Mercury's now stagnant core generate a magnetic field? One potential answer is that the observed magnetic field is a fossil remaining from Mercury's earliest years; perhaps rocks were magnetized long ago when there was a magnetic field, and Mariner 10's magnetometer simply recorded leftover magnetization from the rocks. Another is that the core is indeed still liquid and actively generating the field.

Finding the answer: For insight into Mercury's insides, MESSENGER's laser altimeter will measure the planet's libration – the small amount it "wobbles" as it spins on its axis. By combining this measurement with what we learn about Mercury's gravity from radio science experiments, scientists will be able to deduce the size of the planet's core and how much of it is liquid or solid. The magnetometer should also be able to tell if the magnetic field stems from activity inside the planet, or from magnetic areas of the surface.

Question 4: What is the nature of Mercury's magnetic field?

The solar wind – the ever-expanding atmosphere of the Sun – forces constant change in Earth's magnetic field. We see the effects of these changes in the form of the aurora, electrical power blackouts, and TV and radio interference. Mariner 10 found that where the solar wind interacted with Mercury, the particles changed in a way that suggested the effects of an internal magnetic field. A better understanding of an internal magnetic field smaller, weaker and much closer to the Sun than Earth's will teach us more about our own magnetosphere – this is comparative planetology at its best.

Earth has a dipolar magnetic field, shaped like a bar magnet's field, with positively and negatively charged poles. Mercury's field also appears to be dipolar. In contrast, the Moon and Mars lack a global dipolar magnetic field, but have local magnetic fields centered on different spots that are relicts. It's not clear how much of Mercury's field comes from smaller local fields (like on Mars or the Moon), and how much is indeed global, produced deep within the planet.

Finding the answer: MESSENGER's magnetometer will examine Mercury's magnetic field over four Mercury years (each 88 Earth days) to determine its strength and how it varies with position, altitude and time. The magnetometer and energetic particle and plasma spectrometer will also sense the magnetic field's responses to solar activity, and help separate the internal from externally induced components of the field.

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

In the early 1990s, scientists using radar (i.e., microwaves) to observe Mercury noticed that something inside craters near its poles was strongly reflecting the radar pulses. To most experts the materials looked a lot like what would be expected from molecules such as water ice.

At first, it seems ludicrous to even think about water ice on a planet where "daytime" temperatures near the equator can soar to 450 degrees Celsius (840 degrees Fahrenheit). But since the planet does not tilt – its spin axis is nearly perpendicular to its equator – sunlight does not reach the floors and walls of polar craters, and temperatures inside these craters stay perpetually cold. Could water molecules from comets and meteorites have become trapped in the shadowy corners of these cold craters, frozen and accumulated over billions of years? Or, could water vapor have seeped out from inside the planet and frozen out near the poles? Such ice deposits could be insulated by thin layers of dust and other material ejected by impacts, but still visible to the penetrating waves of radar. Some scientists think the material isn't water ice but something else, such as sulfur, derived from minerals in the surface rocks. This enigma is an important topic in the comparative planetology of the Moon, Mercury and Mars.

Finding the answer: It will be a challenge to figure out what the deposits are, because they will be invisible to many of MESSENGER's instruments. The very shadows that preserve the ice deposits so close to the solar inferno keep them from being illuminated by the Sun. MESSENGER's gamma-ray and neutron spectrometers – designed to pinpoint key elements on Mercury's surface – will aim toward these polar craters and may be able to sense if they are lined with water ice or other materials. Looking in the same direction, the ultraviolet and energetic particle spectrometers could also detect hydroxyl (OH) or sulfur emissions from the deposits.

Question 6: What volatiles are important at Mercury?

Mercury is surrounded by an extremely thin layer of gas – so thin that, unlike in the atmospheres of Venus, Earth and Mars, the molecules surrounding Mercury don't collide with each other. Instead, they bounce from place to place on the surface, almost like rubber balls. (Such an atmosphere is also referred to as an "exosphere.")

We know of six elements in Mercury's atmosphere: hydrogen, helium, oxygen, sodium, potassium and calcium. These elements are relatively abundant and are particularly easy to detect with Earth-based telescopes. Each element in the atmosphere has a different origin. Hydrogen and helium come (at least in part) from the solar wind. Some of the hydrogen and oxygen may also come from ice that came aboard comets and meteorites that hit the planet. The sodium, potassium, calcium and some of the oxygen is thought to come from rocks on the surface.

Finding the answer: MESSENGER will measure the composition of Mercury's atmosphere with its ultraviolet and energetic particle spectrometers. By comparing these data with X-ray and gamma-ray measurements of the surface rocks, scientists will gain invaluable clues on the origin of each element in the planet's atmosphere, and learn more about where they came from.

Science Groups

The MESSENGER science team, which includes 23 investigators from 13 research institutions, is divided into four broad disciplinary groups. The *Geology* group, chaired by Dr. James Head III, Brown University, will interpret data on Mercury's geologic history. *Geochemistry*, led by Dr. William Boynton, University of Arizona, will interpret measurements of Mercury's surface composition. *Geophysics*, chaired by Dr. Maria Zuber, Massachusetts Institute of Technology, will cover the altimetry and gravity measurements. The *Atmosphere and Magnetosphere* group, led by Dr. Stamatios Krimigis, the Johns Hopkins University Applied Physics Laboratory, will analyze data on Mercury's magnetic field, atmosphere, and energetic particle and thermal plasma characteristics.

MESSENGER Science Team

Sean C. Solomon, *Carnegie Institution of Washington* (Principal Investigator)
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Mercury's First Visitor: 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 a TV camera and several spectrometers, Mariner 10 was launched toward Venus on November 3, 1973. After flying past Venus on February 5, 1974 – and snapping the first close-up images of the planet's smooth layers of 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 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 scales down to 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.

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

- *Mariner 10 Archive Projec*t (Mark Robinson, Northwestern University) – http://cps.earth.northwestern.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 may soon have company in its study of Mercury. BepiColombo, a collaboration between the European Space Agency and the Japanese Space Agency (JAXA) scheduled to launch in 2012, plans to put 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.

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 will return the cometary dust to Earth in January 2006.

Genesis, launched in August 2001, spent 2½ years collecting solar wind particles for return to Earth in September 2004. The samples will help scientists learn what the young solar system was like and help identify the elements that formed the planets.

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 aims to send an impactor into the path of comet Tempel 1 in July 2005, creating a football field-sized crater seven stories deep and revealing never-before-seen materials and structural details from inside a comet. Deep Impact launches in December 2004.

Dawn launches in May 2006 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 fall 2007 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.

Discovery also includes a Mission of Opportunity – not a complete Discovery mission, but a piece of a larger non-NASA mission. 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.

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

Mission Overview

MESSENGER is a scientific investigation of Mercury, the least explored of the terrestrial ("rocky") planets that also include Venus, Earth and Mars. Understanding Mercury and how it formed is critical to better understanding the conditions on and evolution of the inner planets.

The MESSENGER project takes advantage of clever mission designs, tougher lightweight materials and miniature technologies all developed in the three decades since Mariner 10 flew past Mercury. 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.

After launch, MESSENGER will match Mercury's orbit by flying past Earth once, Venus twice and Mercury three times, using the planets' gravity to adjust its path each time. The Mercury flybys, which will include pictures and measurements of the planet's previously "unseen" side, provide information critical to planning and carrying out an orbit study that lasts four Mercury years, or one Earth year.

Launch

MESSENGER will lift off from Launch Complex 17B at Cape Canaveral Air Force Station, Fla., on a three-stage Boeing Delta II expendable launch vehicle. The 13-day launch period opens August 2, 2004, at 2:16:11 a.m. (EDT). A 12-second launch opportunity is available each day.

The Delta II 7925-H (heavy lift) model is 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 2.9-meter (9.5-foot) diameter payload fairing, the launch vehicle is about 40 meters (or 130 feet) tall.

The first stage uses a Rocketdyne RS-27A main engine, which provides nearly 890,000 newtons (200,000 pounds) of thrust by reacting RP-1 fuel (thermally stable kerosene) with liquid oxygen. The nine boosters are each 1,168 millimeters (46 inches) in diameter and fueled with enough hydroxyl-terminated polybutadiene solid propellant to provide about 556,000 newtons (125,000 pounds) of thrust apiece. (Note: A newton is the unit of force needed to accelerate one kilogram of mass to one meter per second in one second.)

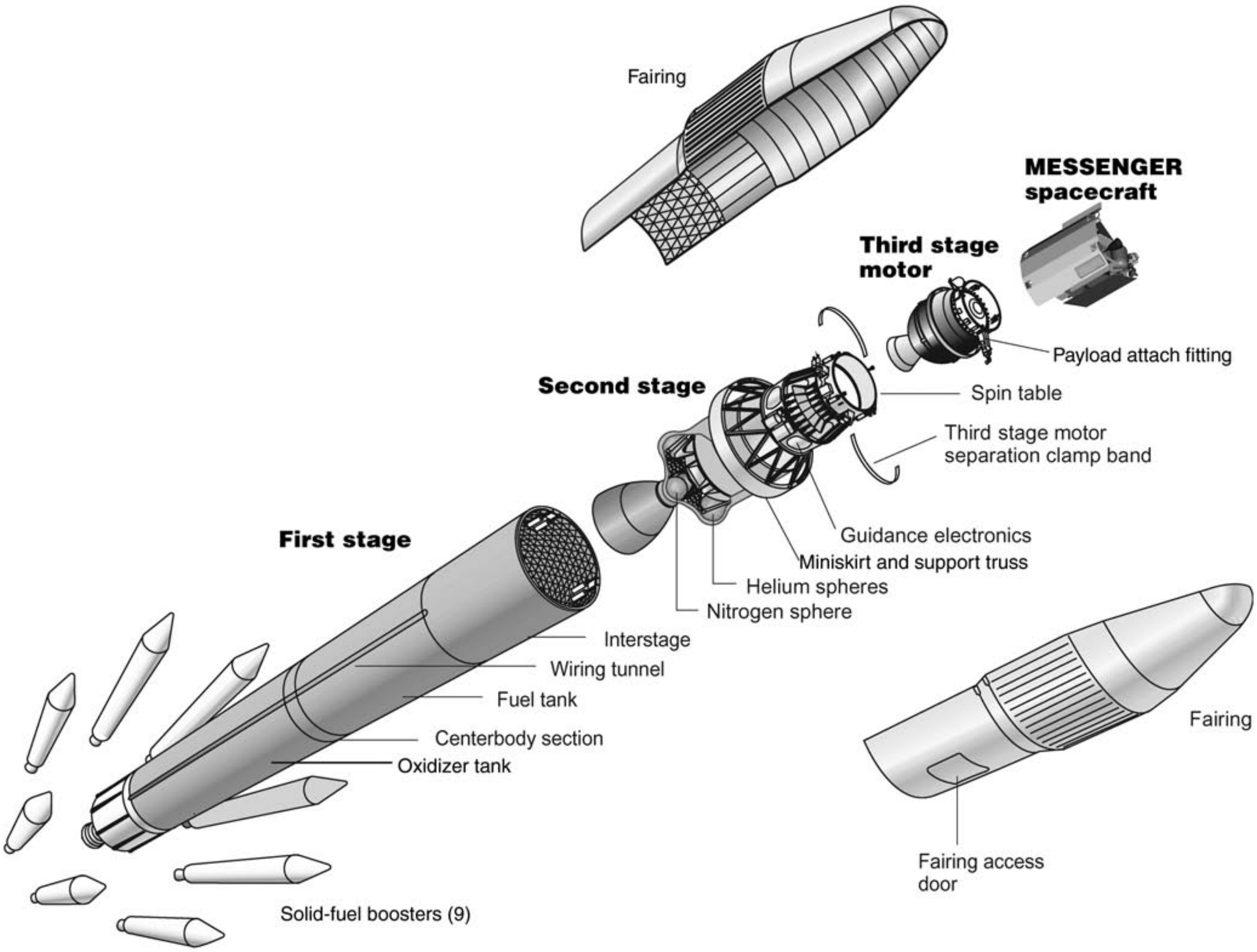
The second stage is powered by an Aerojet AJ10-118K engine, which produces about 44,000 newtons (9,900 pounds) of thrust. The engine uses Aerozine 50 fuel, a mixture of hydrazine and dimethyl hydrazine, reacted with nitrogen tetroxide as an oxidizer.

A Thiokol Star-48B solid-fuel rocket powers the third stage. With a propellant made mainly of ammonium perchlorate, it sends MESSENGER into its heliocentric (Sun-centered) orbit with a final boost of about 66,000 newtons (14,850 pounds).

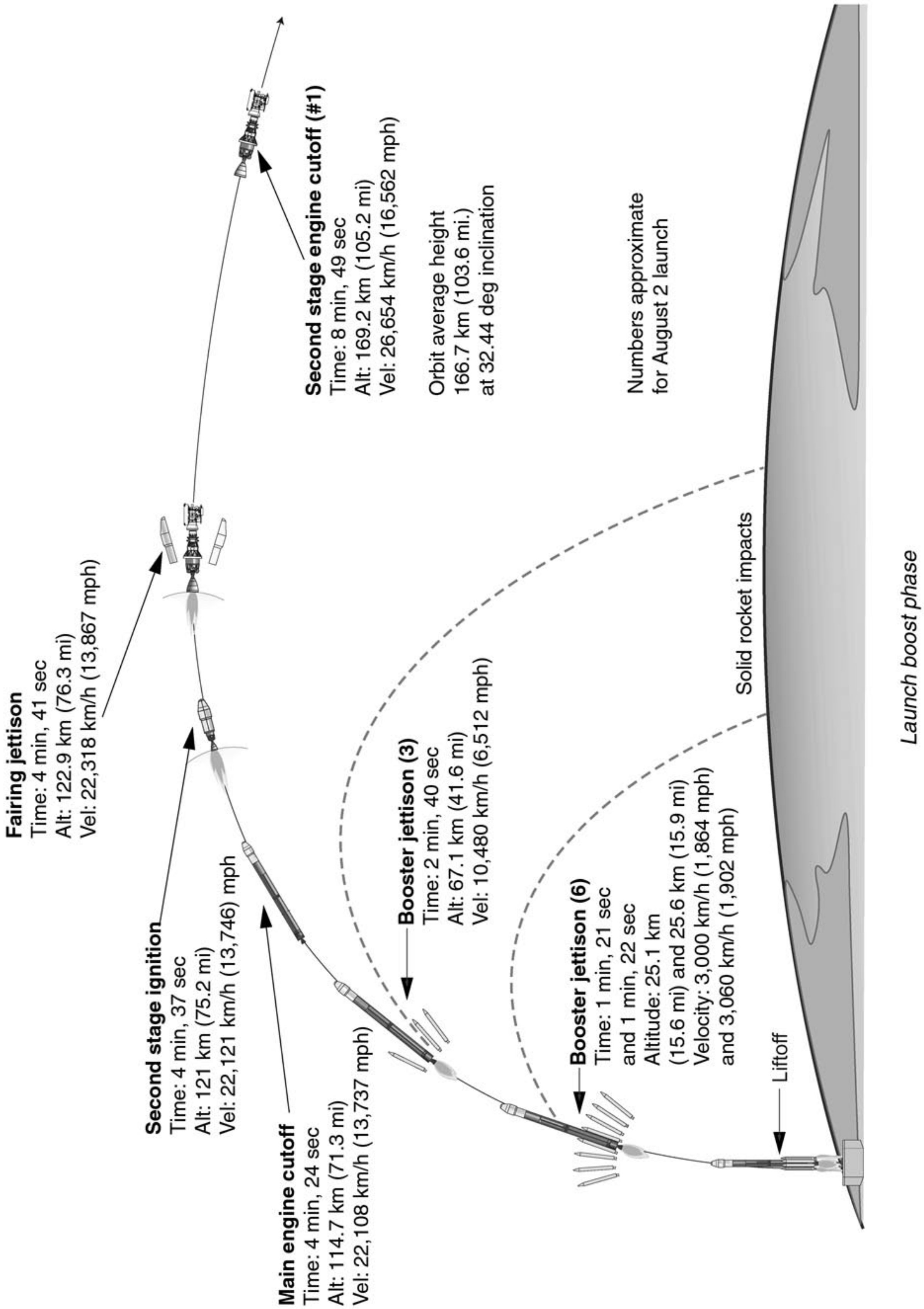
MESSENGER Launch Times

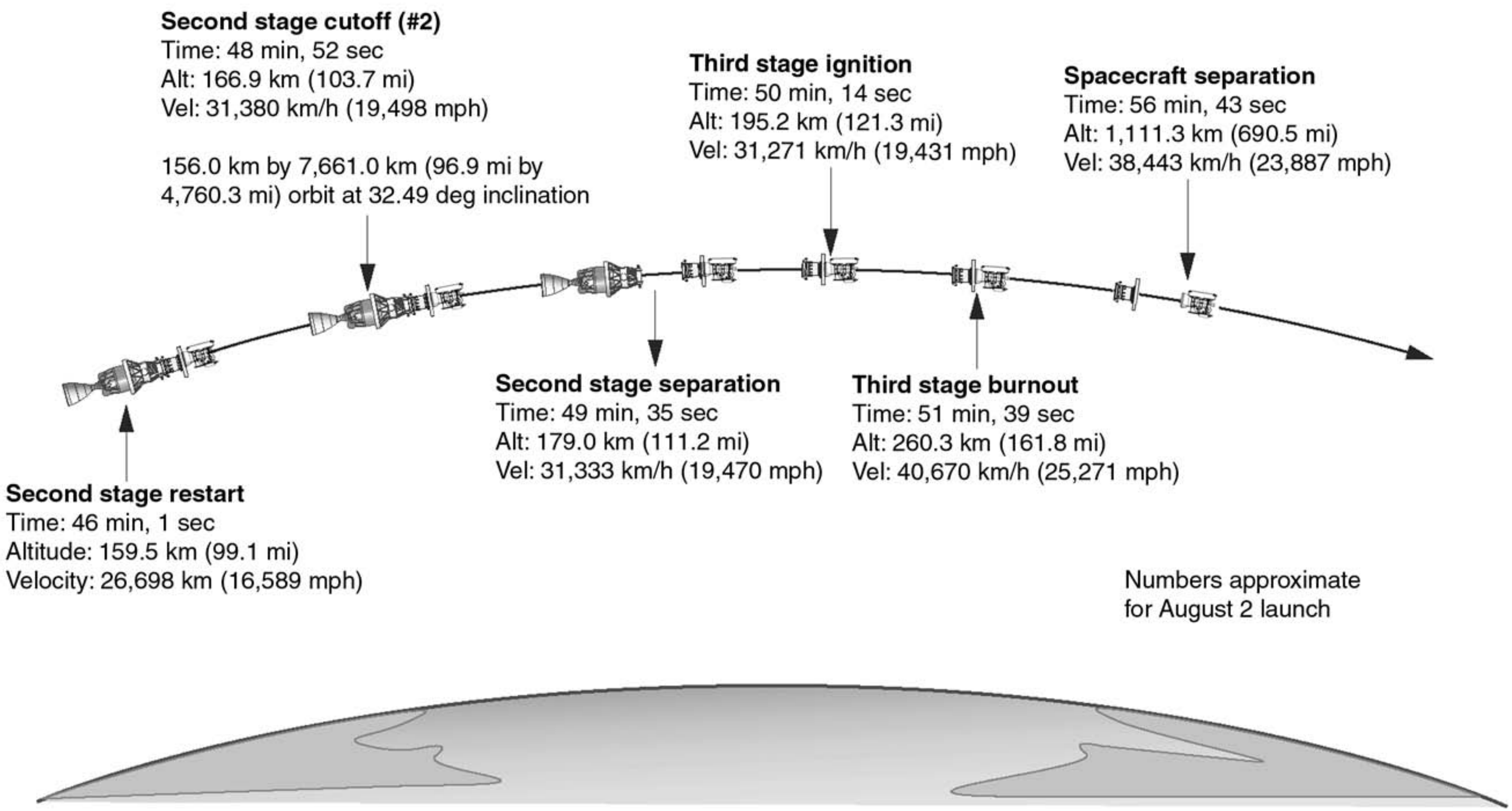
Date	Eastern Daylight Time (EDT)
August 2	2:16:11 (a.m.)
August 3	2:15:56
August 4	2:15:22
August 5	2:15:12
August 6	2:14:58
August 7	2:14:47
August 8	2:14:22
August 9	2:14:07
August 10	2:13:54
August 11	2:13:49
August 12	2:13:42
August 13	2:13:29
August 14	2:13:41

Times denote opening of 12-second launch window.



Delta II rocket with MESSENGER


Second stage engine cutoff (#1)
Time: 8 min, 49 sec
Alt: 169.2 km (105.2 mi)
Vel: 26,654 km/h (16,562 mph)
Orbit average height
166.7 km (103.6 mi.)
at 32.44 deg inclination
Numbers approximate
for August 2 launch
Fairing jettison
Time: 4 min, 41 sec
Alt: 122.9 km (76.3 mi)
Vel: 22,318 km/h (13,867 mph)
Solid rocket impacts
Launch boost phase
Booster jettison (3)
Time: 2 min, 40 sec
Alt: 67.1 km (41.6 mi)
Vel: 10,480 km/h (6,512 mph)
Second stage ignition
Time: 4 min, 37 sec
Alt: 121 km (75.2 mi)
Vel: 22,121 km/h (13,746) mph
Booster jettison (6)
Time: 1 min, 21 sec
and 1 min, 22 sec
Altitude: 25.1 km
(15.6 mi) and 25.6 km (15.9 mi)
Velocity: 3,000 km/h (1,864 mph)
and 3,060 km/h (1,902 mph)
Main engine cutoff
Time: 4 min, 24 sec
Alt: 114.7 km (71.3 mi)
Vel: 22,108 km/h (13,737 mph)
Liftoff

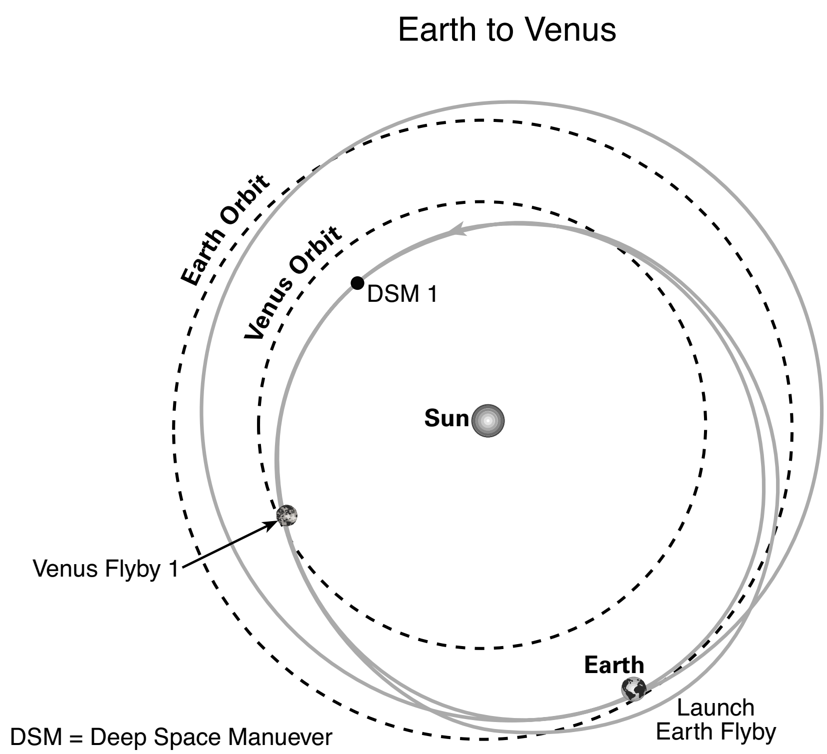


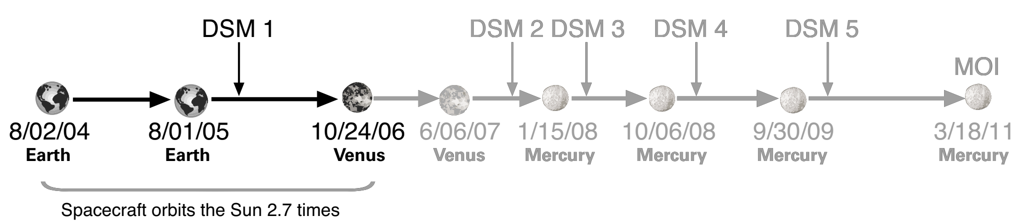
Launch injection phase

Early Operations and Earth Flyby

For several weeks after launch, mission controllers will turn on and check MESSENGER's major subsystems and instruments. A year after launch the spacecraft returns for a 2,866-kilometer (1,777-mile) altitude Earth flyby, using our planet's gravity to redirect itself toward Venus. Flying past Earth will also allow the team to calibrate part of MESSENGER's science payload – one planned test calls for the camera and atmospheric-surface spectrometer to point toward the Moon.

Through some of its early cruise MESSENGER will fly with its back toward the Sun, keeping its electronics warm without using precious power for heaters. At other times, when the spacecraft is just within Earth's orbit, it will fly with its shade toward the Sun. Nearly a year after the Earth flyby, operators will command it to "flip" on its horizontal axis one more time – after that, MESSENGER's sunshade faces the Sun for the rest of the mission.





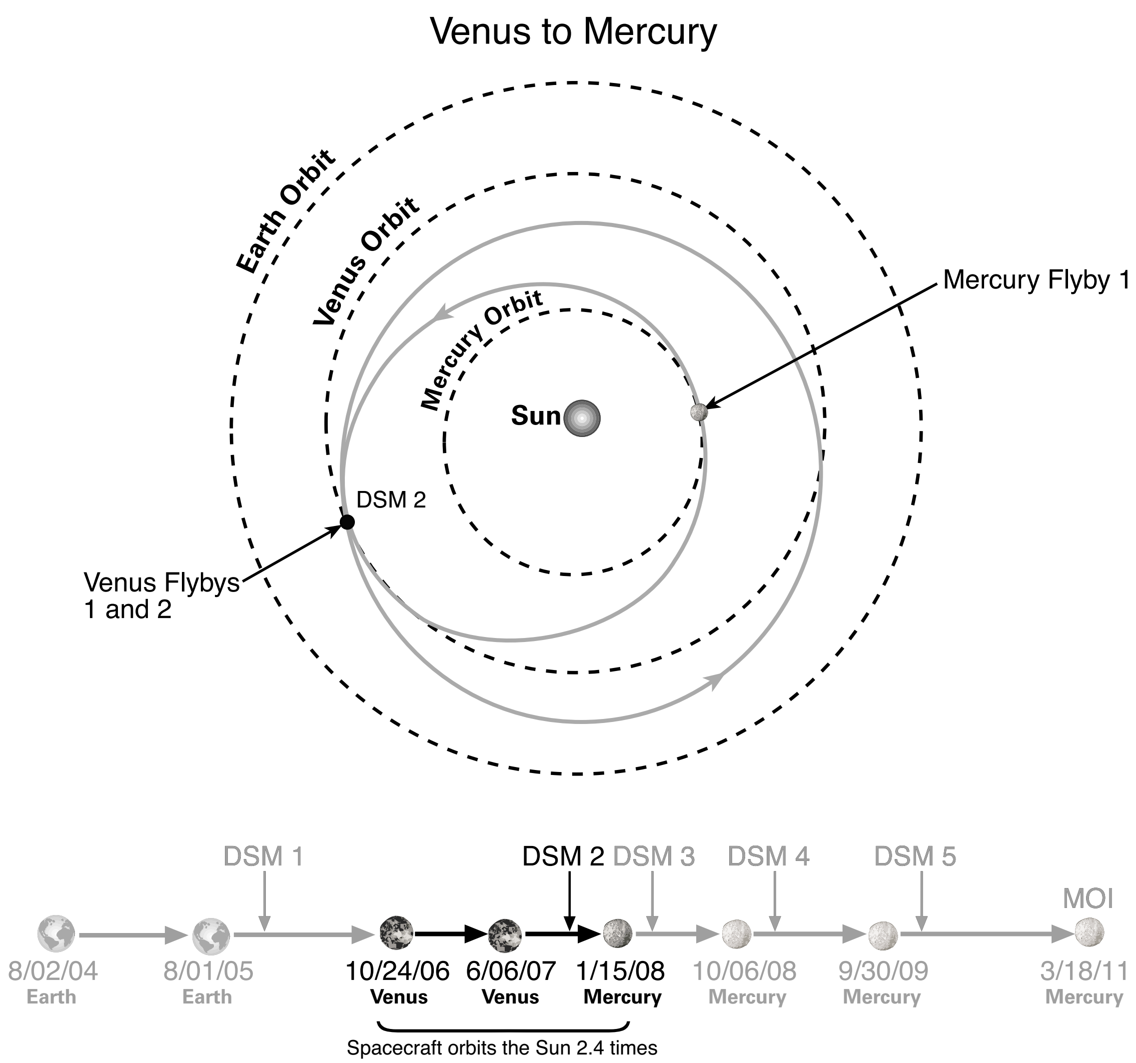
Venus Flybys

MESSENGER's path to Mercury takes it past Venus twice. The spacecraft uses the tug of Venus' gravity to resize and rotate its trajectory closer to Mercury's orbit. In October 2006, MESSENGER flies 3,612 kilometers (2,239 miles) above Venus' surface, reducing its orbit's perihelion and aphelion (minimum and maximum distance from the Sun) and increasing the orbit inclination – the tilt angle relative to Earth's orbit around the Sun. The approaching spacecraft will view a brightly sunlit Venus, with a mostly dark view on departure.

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 designed the concept in the mid-1980s. MESSENGER adapts this mission design; without these flybys, MESSENGER would move so fast past Mercury (about 10 kilometers per second) that no existing propulsion system could slow it down enough to enter into orbit.

MESSENGER returns for another sunlit look at the planet in June 2007, coming 300 kilometers (186 miles) above Venus, and moving a little closer to the farthest point in Mercury's orbit. This pass increases the inclination of MESSENGER's orbit to match that of Mercury.

Aside from course corrections, the flybys give MESSENGER engineers and scientists a chance to check out the instruments and practice observing techniques for the three Mercury flybys.



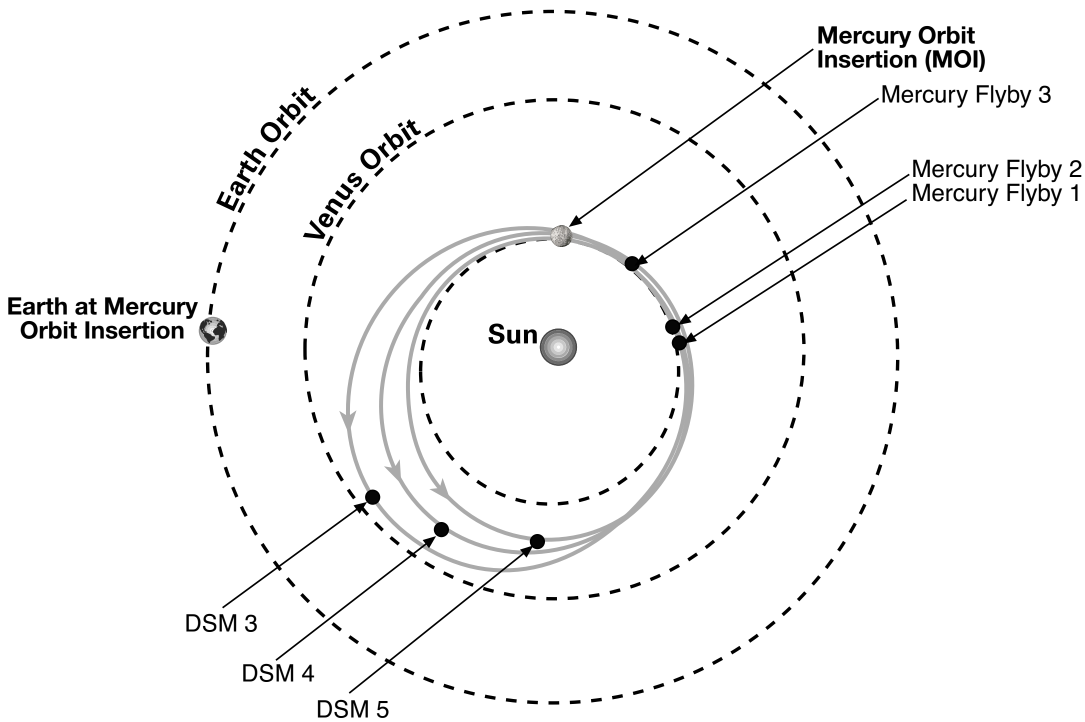
Reaching Mercury

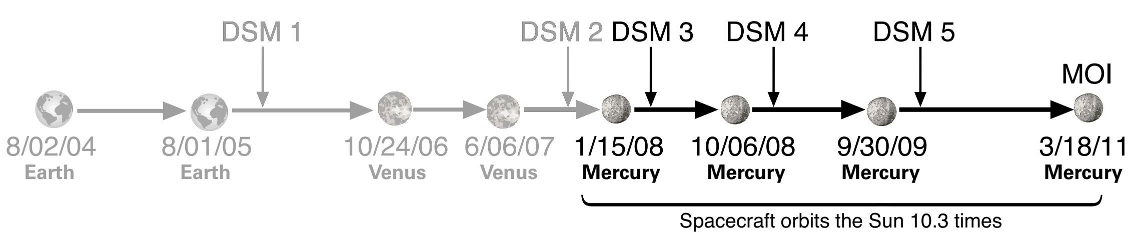
Three 200-kilometer (124-mile) minimum-altitude Mercury flybys, each followed about two months later by a course-correction maneuver, put MESSENGER in position to enter Mercury orbit in March 2011.

During the flybys – set for January 2008, October 2008 and September 2009 – the spacecraft departs with sunlit views of the planet. MESSENGER's instruments can view each side of the never-before-imaged hemisphere of Mercury soon after reaching minimum altitude.

MESSENGER will map nearly the entire planet in color, image most of the areas unseen by Mariner 10, and measure the composition of the surface, atmosphere and magnetosphere. It will be the first new data from Mercury in more than 30 years – and invaluable for planning MESSENGER's yearlong orbital mission.

Mercury Flybys



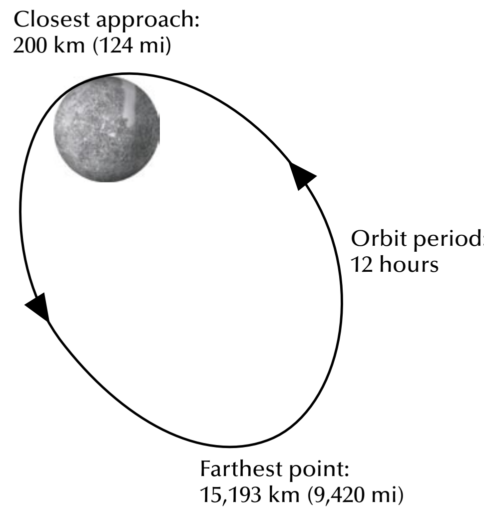


For a full-color look at MESSENGER's entire trajectory, visit http://messenger.jhuapl.edu/the_mission/mission_design.html.

Science Orbit: Working at Mercury

For one year MESSENGER will operate in a highly elliptical (egg-shaped) orbit around Mercury, 200 kilometers (124 miles) above the surface at the closest point and 15,193 kilometers (9,420 miles) at the farthest. The plane of the orbit is inclined 80 degrees to Mercury's equator, and the low point in the orbit comes at 60 degrees north latitude. MESSENGER will orbit Mercury twice every 24 hours; for eight of those hours it will be oriented for sending data to Earth.

Orbit insertion occurs on March 18, 2011. Using 30 percent of its propellant, MESSENGER will fire its large thruster and slow down by just about 0.9 kilometers (about a half mile) per second, coming to a virtual stop relative to Mercury. The first orbit insertion maneuver (lasting about 14 minutes) places the spacecraft into a stable orbit; it also sets up a much shorter "cleanup" maneuver two days later near the orbit's lowest point.



MESSENGER's 12-month orbit 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, solar gravity and radiation 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.

Mission Operations

MESSENGER's mission operations are conducted from the Mission Operations Center 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 thrusters and refine its path to and around Mercury.

Like all NASA interplanetary missions, MESSENGER will rely on the agency's Deep Space Network 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 will include three 8-hour contacts a week during the cruise phase and daily 8-hour sessions during the orbit at Mercury.

The Science Operations Center, also located at APL, will work with Mission Operations to plan instrument activities, as well as validate, distribute, manage and archive MESSENGER's science data.

Mission Timeline

August 2-14, 2004: Launch from Cape Canaveral Air Force Station on a Boeing Delta II rocket
August 1, 2005: Earth Flyby
October 24, 2006: Venus Flyby 1
June 6, 2007: Venus Flyby 2
January 15, 2008: Mercury Flyby 1
October 6, 2008: Mercury Flyby 2
September 30, 2009: Mercury Flyby 3
March 18, 2011: Orbit of Mercury begins
March 2012: Mercury orbit/data collection ends
March 2013: Final data analysis/archiving complete

Note: Flyby and orbit dates reflect launch on August 2, 2004.

The Spacecraft

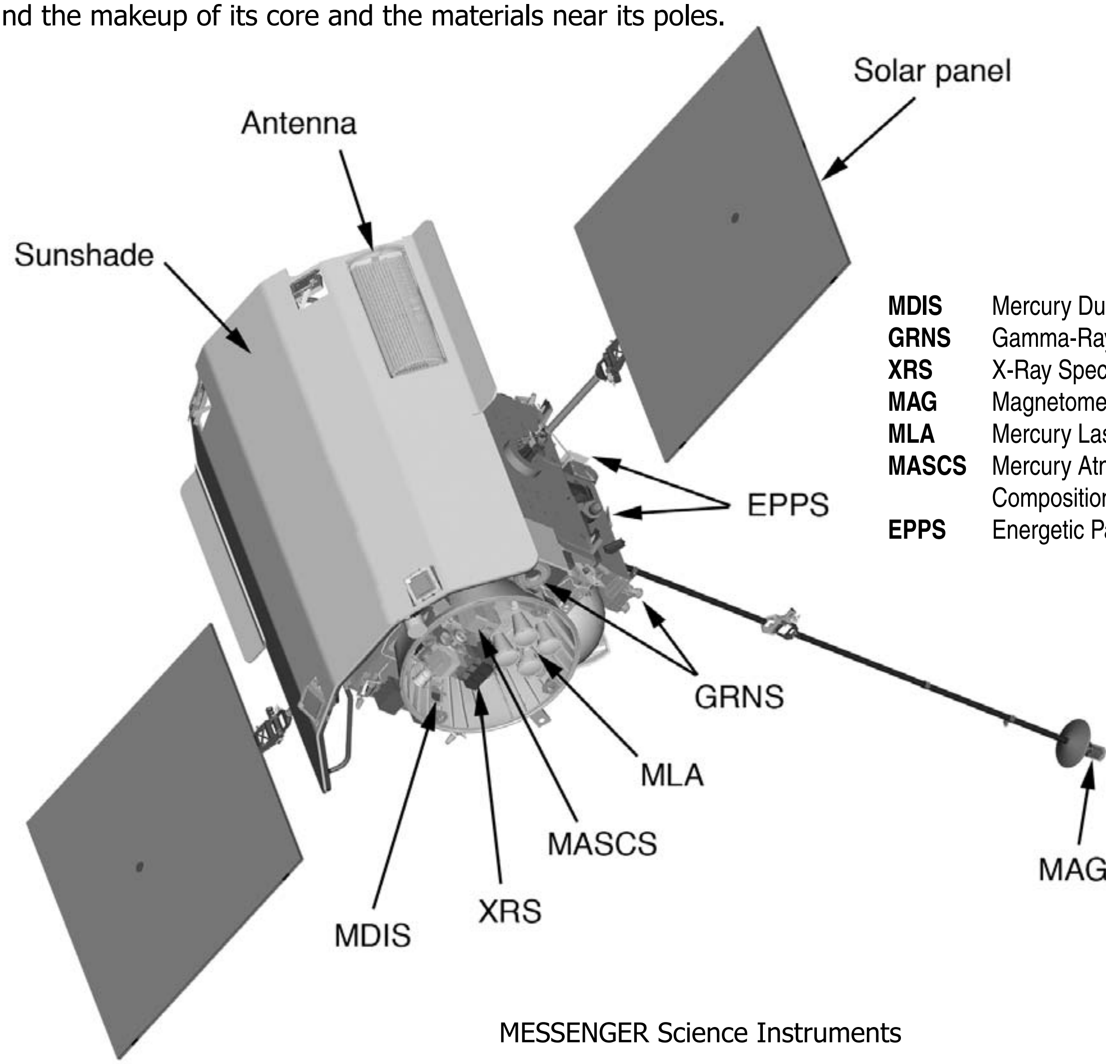
After Mariner 10's visits to Mercury the space science and engineering communities yearned for a longer and more detailed look at the innermost planet – but that closer look, ideally from orbit, presented formidable technical obstacles. A Mercury orbiter would have to be tough, with enough protection 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 and slow the spacecraft down enough for Mercury's gravity to capture it. And it would have to be compact enough to lift off on a conventional and cost-effective rocket.

Designed and built by the Johns Hopkins University Applied Physics Laboratory – with contributions from organizations in 24 states and six countries – 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 (1,323 pounds) of propellant that accounts for 55 percent of MESSENGER's total launch weight.

To fit behind the 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 rocket, the largest launch vehicle allowed under NASA's Discovery Program of lower-cost space science missions.

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.



MDIS	Mercury Dual Imaging System
GRNS	Gamma-Ray and Neutron Spectrometer
XRS	X-Ray Spectrometer
MAG	Magnetometer
MLA	Mercury Laser Altimeter
MASCS	Mercury Atmospheric and Surface Composition Spectrometer
EPPS	Energetic Particle and Plasma Spectrometer

MESSENGER Science Instruments

Mercury Dual Imaging System

Mass: 7.9 kilograms (17.4 pounds)

Peak Power: 10 watts

Development: Johns Hopkins University Applied Physics Laboratory, Laurel, Md.

The multispectral **MDIS** has wide- and narrow-angle imagers – 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 repoint the spacecraft and allowing it to follow the stars and other optical navigation guides.

The wide-angle camera has a 10.5-degree field of view and can observe Mercury through 12 different filters across the wavelength range 400 to 1,100 nanometers (visible and near-infrared light). Multispectral 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-degree field of view, allowing extremely detailed analysis of features as small as 18 meters (about 60 feet) across.

Gamma-Ray and Neutron Spectrometer

Mass: 13.1 kilograms (31 pounds)

Peak Power: 23.6 watts

Development: Johns Hopkins University Applied Physics Laboratory

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

The *Gamma-Ray Spectrometer* measures gamma rays emitted by the nuclei of atoms on Mercury's surface when 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.

The *Neutron Spectrometer* will map 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 small 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.

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 degrees Celsius, or –298 degrees Fahrenheit.

X-Ray Spectrometer

Mass: 3.4 kilograms (7.5 pounds)

Peak Power: 11.4 watts

Development: Johns Hopkins University Applied Physics Laboratory

XRS will map the elements in the top millimeter of Mercury's crust using three gas-filled detectors pointing at the planet and one silicon solid-state detector pointing at the Sun. The planet-pointing detectors measure fluorescence, the X-ray emissions coming from Mercury's surface after solar X-rays hit the planet.

XRS detects emissions from elements in the 1-10 kiloelectron-volt 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-degree 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. A small, thermally protected, solar-flux monitor mounted on MESSENGER's sunshade tracks the X–rays bombarding the planet.

Magnetometer

Mass (including boom): 4.4 kilograms (9.7 pounds)

Peak Power: 4.2 watts

Development: NASA Goddard Space Flight Center, Greenbelt, Md., and the Johns Hopkins University Applied Physics Laboratory

A three-axis, ring-core fluxgate detector, **MAG** will characterize 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) boom that keeps it away from the spacecraft's own magnetic field. 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: 38.6 watts

Development: NASA Goddard Space Flight Center

MLA will map 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: 8.2 watts

Development: 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 Visible Spectrometer* will determine the composition and structure of Mercury's exosphere – the 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-Infrared Spectrograph* 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.

Energetic Particle and Plasma Spectrometer

Mass: 3.1 kilograms (6.8 pounds)

Peak Power: 7.8 watts

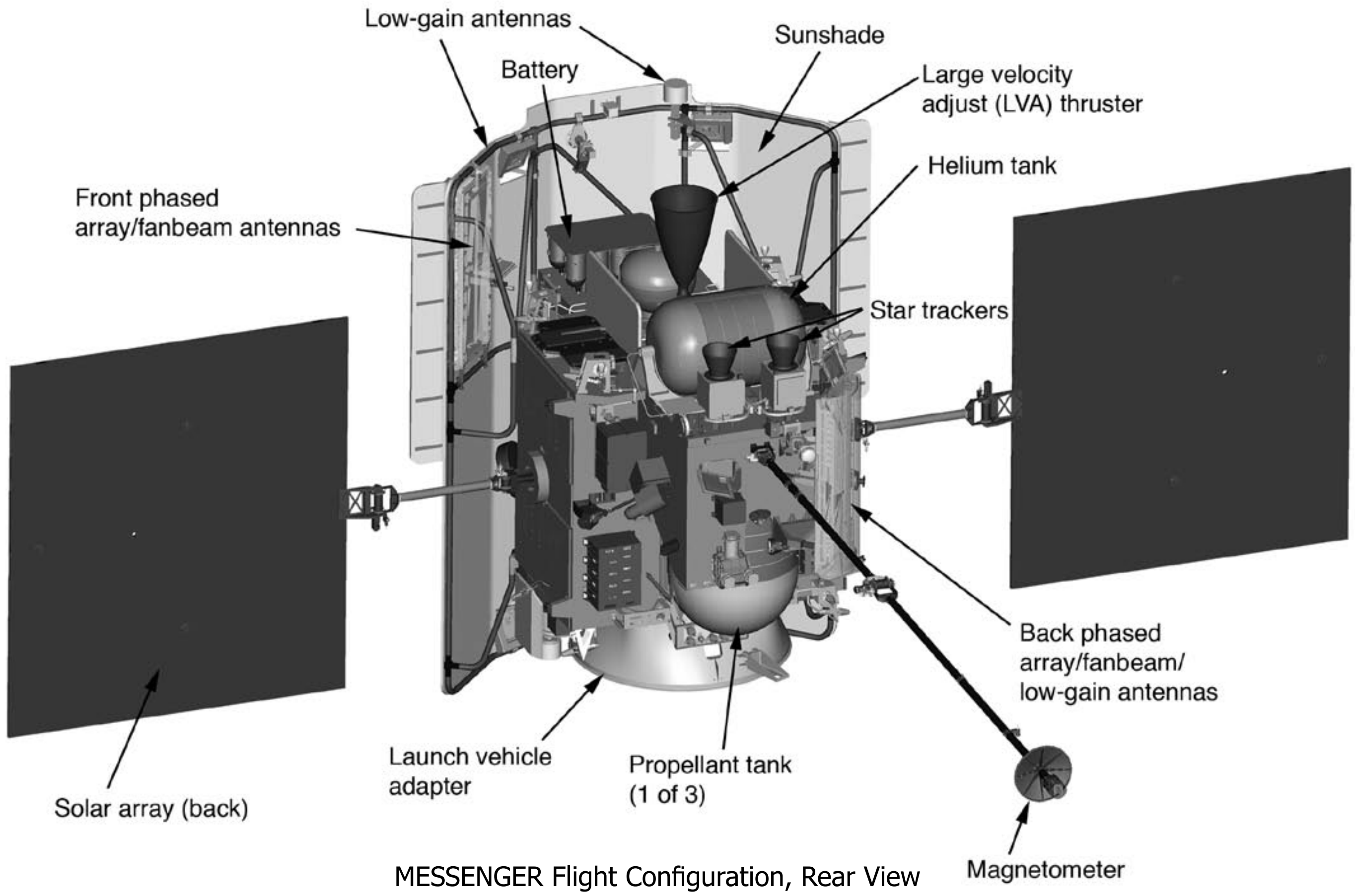
Development: University of Michigan, Ann Arbor, and the Johns Hopkins University Applied Physics Laboratory

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-degree field of view for measuring the energy spectra, atomic composition 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 altimetry investigation to determine the size and condition of Mercury's core. NASA's Goddard Space Flight Center leads the Radio Science experiment.

Spacecraft Systems and Components



MESSENGER Flight Configuration, Rear View

Thermal

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's orbit. The Sun also 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 degrees C (698 degrees F) when Mercury is closest to the Sun, behind it the spacecraft will operate at room temperature, around 20 degrees C (68 degrees F). Multilayered insulation covers most of the spacecraft.

Radiators and 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 385-485 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 67 percent mirrors (called optical solar reflectors) and 33 percent 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 degrees Celsius, or 302 degrees 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" thruster requires a combination of hydrazine and an oxidizer, nitrogen tetroxide. Fuel and oxidizer are stored in custom-designed, lightweight titanium tanks integrated into the spacecraft's composite frame. Helium pushes the fuel and oxidizer through the system to the engines.

At launch the spacecraft will carry about 600 kilograms (1,323 pounds) of propellant – and use nearly 30 percent of it during the maneuver that starts the orbit at 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, 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-degree field without moving parts, and during normal operations at least one of the two antennas will point at Earth.

Higher gain antennas send radio signals through a narrower, more concentrated beam than lower gain antennas. High-gain antennas 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 in a single box. The spacecraft carries a pair of identical IEMs for backup purposes; both house a 25-megahertz 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 Macintosh computer. 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 on 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 daily 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 (containing 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 Inertial Measurement Unit 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.

Six 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 the shade faces the Sun. Then ground controllers can analyze the situation while the spacecraft turns its antennas to Earth and awaits instructions – an operating condition known as "safe" mode.

Spacecraft Hardware Suppliers

Structure: ATK Composite Optics, Inc., San Diego; **Propulsion**: Aerojet, Sacramento, Calif.; **Transponder:** General Dynamics, Scottsdale, Ariz.; **Solid State Power Amplifier Converters:** EMS Technologies, Montreal, Canada; **Inertial Measurement Unit:** Northrop Grumman, Woodland Hills, Calif.; **Star Trackers:** Alenia Spazio, Rome, Italy; **Sun Sensors:** Adcole Corporation, Marlborough, Mass.; **Reaction Wheels:** Teldix GmbH, Heidelberg, Germany; **Solar Array Drives:** Moog Inc., East Aurora, N.Y.; **Solar Arrays:** Northrop Grumman Space Technology, Redondo Beach, Calif.; **Battery** (with APL): Eagle Picher Technologies, Joplin, Mo.; **Integrated Electronics Module** (with APL): BAE systems, Manassas, Va.; **Heat Pipes:** Swales Aerospace, Beltsville, Md.

Visit http://messenger.jhuapl.edu/USmap/usmap.html for a full map of MESSENGER participants.

Program/Project Management

Dr. Sean 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 Office of Space Science, Washington.

At NASA Headquarters, Dr. Edward Weiler is the associate administrator for space science. Orlando Figueroa is director of solar system exploration. Dr. Anthony Carro is the MESSENGER program executive and Dr. Thomas Morgan is the MESSENGER program scientist. Dr. John McNamee is the Discovery Program manager.

At APL, David Grant is the MESSENGER project manager and Dr. Ralph McNutt is MESSENGER project scientist. Dr. Robert Farquhar is mission manager and Mark Holdridge is mission operations manager.

The MESSENGER science team includes investigators from the Applied Physics Laboratory; Brown University, Providence, R.I.; Carnegie Institution of Washington; NASA Goddard Space Flight Center, Greenbelt, Md.; Los Alamos National Laboratory, N.M.; Massachusetts Institute of Technology, Cambridge; Northwestern University, Evanston, Ill.; Southwest Research Institute, Boulder, Colo.; University of Arizona, Tucson; University of California, Santa Barbara; University of Colorado, Boulder; University of Michigan, Ann Arbor; and Washington University, St. Louis.

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