The PLANETARY REPORT

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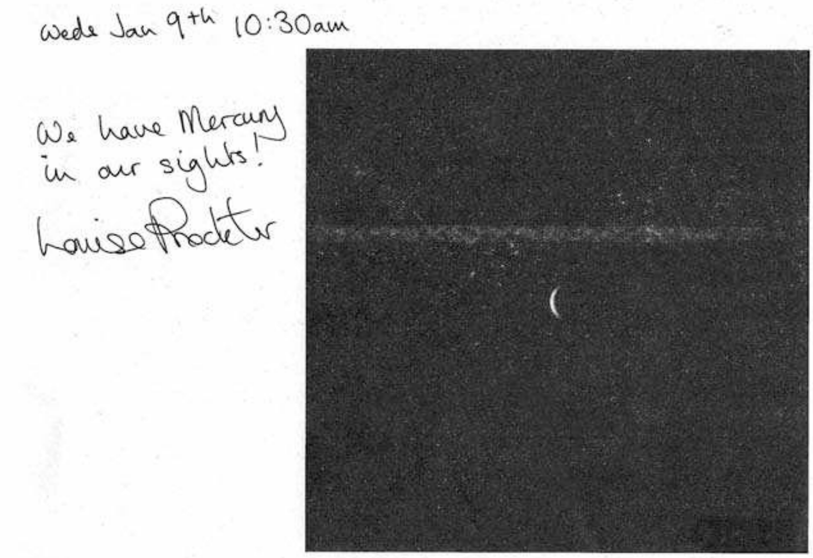
A New Mercury Revealed

MESSEN

ARRIVES

BY RALPH L. MCNUTT, JR. AN

The great Caloris impact basin, the orange circular form at upper righ false-color image, is the largest well-preserved impact basin on Merc to date by spacecraft. The contrasting colors in this view reveal that M surface composition is varied, especially between the floor of Caloris the surrounding region (purple). High-resolution images of the bright spots near the outer edge of Caloris show them to be volcanic vents. taken through the 11 color filters on MESSENGER*'s Wide Angle Camer were compiled to make this false-color portrait.* Image: NASA/Johns Hopkin Applied Physics Laboratory (APL)/Arizona State University/Carnegie Institution of Washington



The tiny sliver in this raw optical navigation image was the MESSENGER *team's first transmittal from Mercury. The spacecraft returned this image as it closed in on its target on January 9, 2008.* Image: NASA/APL/CIW

"We have Mercury in our sights!"

said Louise Prockter, *MESSENGER*'s instrument scientist for the Mercury Dual Imaging System (MDIS). The raw image from the first optical navigation sequence—blemished with artifacts from both the printer and the system—came down at 10:30 a.m. on January 9, 2008, and its receipt was immensely welcome. It meant that *MESSENGER* was on target for the first spacecraft encounter of Mercury in nearly 33 years.

The moment had been almost 12 years in the making. The *MESSENGER* (an acronym for MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission to send the first spacecraft to orbit the solar system's innermost planet had been conceived in March 1996, and now all the hard work and planning were coming to fruition—flawlessly.

From the First Flybys to an Orbiter

The only previous spacecraft to visit Mercury was *Mariner 10*, developed and operated by the Jet Propulsion Laboratory (JPL). *Mariner 10* flew by Mercury three times in 1974–1975, imaged about 45 percent of the surface, discovered Mercury's internal magnetic field

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Right: This color view, captured as MESSENGER *departed from Mercury, shows about 20 percent of the planet that* Mariner 10 *never saw. The image, made with three of the WAC's color filters, was snapped about 45 minutes after* MESSENGER*'s closest approach to Mercury, on January 14, 2008. Like the portion of Mercury seen by* Mariner 10*, this hemisphere is heavily cratered. At upper right is the giant Caloris basin, including its western portions, which had never before been seen by spacecraft.* Image: NASA/APL/CIW

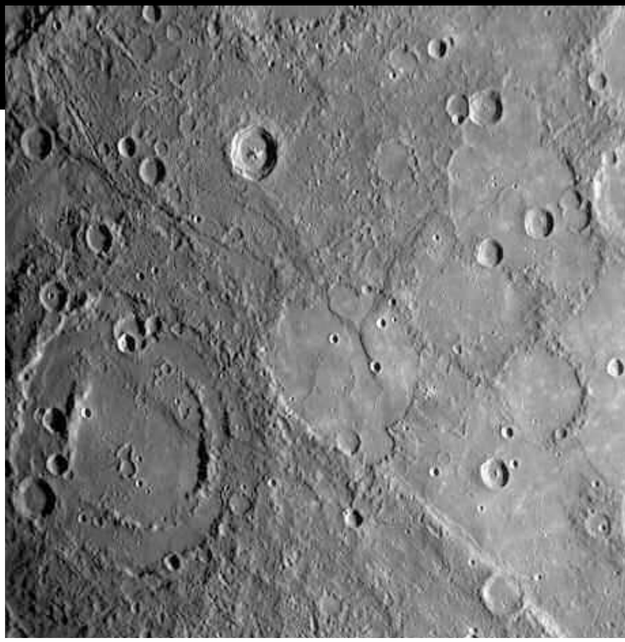
and magnetosphere, and documented that the planet has a tenuous atmosphere.

In the light of *Mariner 10*'s discoveries, the consensus view of the planetary science community was that the next stage of exploration of Mercury should be an orbiter. An orbiter could conduct global high-resolution imaging of the surface, carry out remote geochemical measurements of Mercury's surface composition, map the geometry of Mercury's internal magnetic field, and monitor the structure and composition of Mercury's exosphere and magnetosphere and their changes in response to time of day, solar distance, and solar wind interaction.

In the 1970s, however, it was not known how to insert a spacecraft into orbit about Mercury with a conventional chemical propulsion system. That problem was solved in the mid-1980s by JPL mission design expert Chen-Wan Yen, who discovered trajectories involving multiple gravity assists at Venus and Mercury. A variant of one of these trajectories is employed by *MESSENGER*.

Despite the fact that mission tools were available for a Mercury orbiter, another two decades passed before such a mission could be launched. Mission planners studied several concepts, but they all had price tags too high. The challenges of limited payload mass, large propulsion requirements, and a hazardous thermal environment were finally met by the *MESSENGER* team. They used a combination of scientific focus, miniaturized instrumentation, optimized mission design, and ruthless minimization of spacecraft mass. Only such a holistic approach could address the many cost and technology constraints. Between *Mariner 10* and *MESSENGER*, knowledge of Mercury advanced slowly, even as multiple missions of other types gave us increasingly detailed views of Mars, Venus, and other planets.

In July 1999, *MESSENGER* was selected as the seventh in NASA's Discovery Program series of competed planetary science missions. The mission was confirmed in June 2001. *MESSENGER* was designed, constructed, and tested by the Johns Hopkins University Applied Physics Laboratory (APL), together with several aerospace partners and a science team that is now 46 members strong. APL has operated *MESSENGER* and its payload since launch in August 2004.



Many of the larger impact structures visible here have been filled in, partially to nearly completely, by smooth plains. Several prominent cliffs and ridges mark the locations of faults that formed as a result of horizontal contraction of the crust. This view is approximately 18,000 kilometers (12,000 miles) above the surface and about 500 kilometers (310 miles) across. *Image: NASA/APL/CIW*

Craters as small as 400 meters are visible in this image taken from around 5,800 kilometers (3,600 miles) altitude. The dark curved feature running from top left across to bottom center is Beagle Rupes, a shadowed cliff formed by the cooling and contraction of Mercury's crust. The cliff is the surface manifestation of a huge fault: along the fault, the crust to the right has been thrust over the crust to the left by several kilometers. At upper left is part of the elliptical crater Sweinsdóttir, the rim and floor of which have been deformed by Beagle Rupes. *Image: NASA/APL/CIW*

Water in Mercury's Thin Atmosphere

As *MESSENGER* flew past the night side of Mercury in January, its Fast Imaging Plasma Spectrometer (FIPS) scooped up ions from an atmosphere so tenuous that it's usually called an *exosphere*. FIPS measured the expected amounts of ions such as sodium, potassium, and calcium that previously had been detected as neutral atoms in Mercury's exosphere, but to the science team's great surprise, water also was present—in large amounts.

Mercury has almost no atmosphere because of the planet's close proximity to the Sun; it is continuously blasted by energetic particles from the solar wind, and any significant atmosphere it may ever have formed was eroded away long ago. The particles that *MESSENGER* can find near Mercury got there as a result of the solar wind bombarding Mercury's surface, reacting chemically, and knocking off atoms or molecules, a process called *chemical sputtering*. In a way, then, when FIPS scoops up charged particles from Mercury's atmosphere, it is actually sampling the chemical composition of Mercury's surface.

How could there be water on Mercury? The science team suggests three possibilities, which are not mutually exclusive. First, it has long been theorized (but not yet proved) from Earth-based radar observations that there may be reservoirs of water ice in permanently shadowed crater floors near Mercury's poles. Second, the water could come from comets. Third, the process of chemical sputtering could create water where none existed before, from the ingredients of solar wind and Mercury rock.

—Emily Lakdawalla, Science and Technology Coordinator

Getting to Mercury

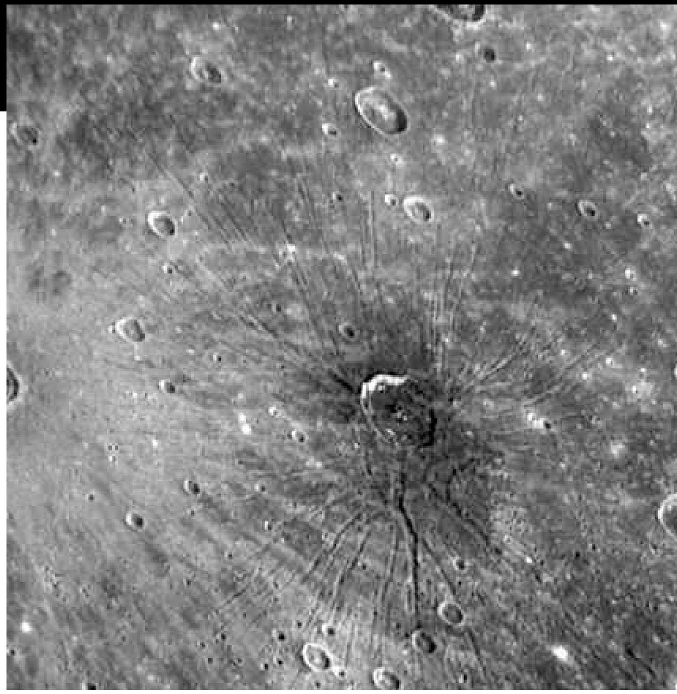
MESSENGER employs a mission design involving six planetary flybys and five major propulsive maneuvers between launch and orbit insertion at Mercury. As of the beginning of 2008, *MESSENGER* had completed a flyby of Earth (August 2005), two flybys of Venus (October 2006 and June 2007), and two of its major propulsive maneuvers.

The Mercury flyby planned for January 14, 2008 was the first of three before orbit insertion can be accomplished at the fourth Mercury encounter, in March 2011. Every flyby has to be completed within a small margin of error if the entire mission design—including insertion into the correct orbit about Mercury—is to be accomplished. The January flyby of Mercury therefore not only was the first opportunity for a close-up view of the innermost planet in more than three decades but also was critical to the success of the rest of the mission.

To the delight of the entire *MESSENGER* team, the January 14 flyby was a success on all counts. *MESSENGER* achieved a closest approach altitude of 201.4 kilometers (125.1 miles) at 7:05 p.m. Universal Time (UTC). The encounter sequence of almost 14,000 commands worked nearly flawlessly, with all instruments operating and all guidance and control sequences executed as planned.

Excluding the optical navigation images and frames used to construct approach and departure movies, MDIS returned 1,213 images of Mercury, including some showing 21 percent of the planet's surface never before seen from a spacecraft, as well as new views of areas imaged by *Mariner 10*. *MESSENGER*'s best images from this flyby were at a resolution of about 150 meters.

This is the southwestern section of Caloris basin. The higher reflectance and well-preserved rays of Cunningham crater at top right are evidence that the crater is relatively young. The pattern of troughs visible here is similar to the pattern seen by Mariner 10 *on the eastern side of the basin floor. This image is approximately 280 kilometers (175 miles) across.* Image: NASA/APL/CIW



Originally nicknamed "the spider," this unique feature at the center of Caloris basin is one of the biggest surprises delivered by MESSENGER *so far. At the center of the spokelike pattern of troughs, now formally named Pantheon Fossae, is a crater named Apollodorus, about 40 kilometers (25 miles) across. Whether the crater-forming impact also led to the formation of the spoke-like troughs is still under investigation by the* MESSENGER *team.* Image: NASA/APL/CIW

A Closer Look at Mercury's Surface

MESSENGER's flyby images capture Mercury's surface and geologic history in intricate detail. They show impact features ranging in size from large multi-ring basins to craters as small as several hundred meters in diameter and preserved to varying degrees. The images permit assessments of the relative ages of major geologic features and of the sequence of geologic processes in a given area. They support the inference that many of the smooth plains on Mercury must have been emplaced as volcanic flows rather than as ejecta deposits from large surface impacts. The photos also document the widespread occurrence, first seen in *Mariner 10* images, of large cliffs and ridges that are the surface expressions of thrust faults formed as the entire planet cooled and contracted.

The Caloris basin has its own special geologic history. A number of large impact craters within the basin excavated material substantially darker than and different in color from the comparatively bright plains that fill the basin floor. *Mariner 10* observations of the eastern floor of Caloris showed that the floor displays two sets of tectonic features—an older set of contractional ridges and a younger set of extensional troughs, interpreted to have formed during an early episode of subsidence and a later episode of uplift, respectively. *Mariner 10* did not, however, image the center or the western half of the basin floor. *MESSENGER* has shown that the western basin floor has a deformational history broadly similar to that of the eastern floor.

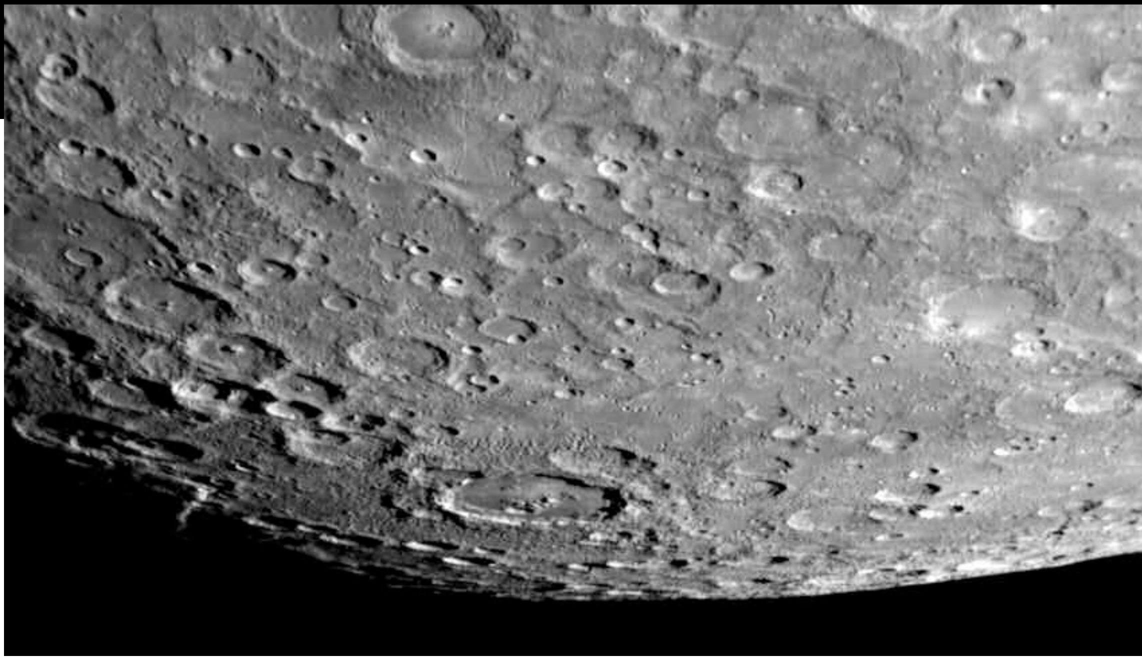
One of the biggest surprises of the *MESSENGER* images is that the center of the Caloris basin floor exhibits a radiating pattern of troughs unlike anything seen elsewhere on Mercury. Near the center of this spokelike pattern of troughs, named Pantheon Fossae, is the crater Apollodorus (named for the reputed architect of the Pantheon in Rome), approximately 40 kilometers (25 miles) in diameter. Whether the impact that formed the crater also led to the formation of the fault-bounded troughs or was simply a coincidental later addition is still under study.

Additional *MESSENGER* images are providing a basis for unraveling the sequence of geologic events on regional scales. Glimpses of the heavily cratered region toward the planet's south pole and the more varied terrain toward the north pole offer hints of what the spacecraft will observe once inserted into a nearly polar orbit about Mercury. Many of the most prominent features imaged for the first time in January 2008 now have new names approved by the International Astronomical Union (IAU), but many more features await future name assignments.

Characterizing the Innermost Planet

MESSENGER's other instruments also returned significant results from the flyby. The magnetometer documented Mercury's internal magnetic field at a closer distance to the planet than was possible with *Mariner 10*. Unlike that earlier spacecraft, *MESSENGER* observed no energetic particles during its flyby, although low solar activity and an unfavorable orientation of the interplanetary magnetic field could have been responsible for that result.

The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) mapped the neutral sodium tail of Mercury for more than 20,000 kilometers (12,500



Glimpses of Mercury's poles offer hints of what MESSENGER *will see once it achieves a nearly polar orbit around the planet. At lower left in this image, looking toward the heavily cratered south pole, a raised crater rim catches sunlight, looking like a wisp of smoke. This region is new to spacecraft "eyes."* Image: NASA/APL/CIW

miles) in the anti-sunward direction, and the Fast Imaging Plasma Spectrometer sensor of the Energetic Particle and Plasma Spectrometer detected a magnetosphere filled with both protons and heavy ions. The heavy ions that originated either from Mercury's surface or by ionization of neutral atoms in the planet's tenuous atmosphere (more properly called an *exosphere*) constitute a remote sampling of Mercury's surface materials (see sidebar on page 14) and provide a measure of the processes that subject those materials to "space weathering."

MESSENGER carried out the first laser ranging to Mercury from a spacecraft and thereby provided the first high-resolution measurements of surface topography. *MESSENGER* was sufficiently close to the surface to obtain ranging results near closest approach only on the night side of the planet, a region not yet imaged by spacecraft. (*MESSENGER* will view this area in sunlight during its second Mercury flyby, in October 2008.) The radar at the Arecibo Observatory captured images of this portion of Mercury's surface, permitting some portions of the altimetric profile to be correlated with craters seen in the radar images, but more confident interpretation of altimetry will be possible once spacecraft ranging and imaging observations can be combined.

MESSENGER also conducted the first reflectance spectroscopy from a spacecraft at wavelengths from the ultraviolet to the near-infrared. Understanding the surface composition and mineralogy of Mercury is an important goal of the *MESSENGER* mission, supported by the Gamma-Ray and Neutron Spectrometer, X-Ray Spectrometer, and MASCS instruments. Both the Visible and Infrared Spectrograph (VIRS) and Ultraviolet and Visible Spectrometer (UVVS) sensors on MASCS were able to view Mercury's surface. The distinct spectral signatures of "mature" and "fresh" material show up clearly. The mission team is continuing its analysis of these spectral data and designing observational campaigns for the next flybys that will elucidate the diversity of terrain types by spectral characteristics.

Whetting Our Appetites for More

Planetary flybys, although short events, require long-term planning. Preparation for the first Mercury flyby began prior to *MESSENGER*'s second Venus flyby in June 2007. That encounter enabled the sequencing team to test much of the software that would be used for the first Mercury flyby. The readiness review for that Mercury flyby was held in October 2007, and final planning continued through the calendar year. By the end of 2007, plans were in place for the science team to gather at APL for the encounter.

Team members began arriving at APL on Sunday night, January 13, 2008. Optical navigation images from the previous several days showed a crescent Mercury growing in the field of view.

At 7:56 a.m. local time (Eastern Standard Time, EST) on Monday, January 14, the spacecraft transitioned from high-rate downlink to beacon mode as it was reoriented for radio science and, later, imaging measurements. The majority of the science team was on site by Monday afternoon as *MESSENGER* made its closest approach, just after 2:00 p.m. EST, when the only evident signature of the planet was its occultation of the signal from the spacecraft. The recovery of the signal and the expected Doppler shift in the downlink frequency brought a wave of relief to the entire team. About 22 hours remained before the last elements of the encounter sequence would finish and high-rate data downlink would resume.

The next day, January 15, at 11:30 a.m. EST, the high-rate communication signal from *MESSENGER* was reacquired. Telemetry data indicated that the encounter sequence had executed as planned. That afternoon, images and other data began to flow into the Mission Operations Center (MOC) and the Science Operations Center (SOC) at APL.

With anticipation mounting, the team at the SOC waited for the appearance of the first closeup image—one of the Wide-Angle Camera frames of the full planet. Starting that afternoon, the science team began meeting on a twice-daily basis: at 9:00 a.m. to plan the day and at 4:00 p.m. to discuss the day's results, spacecraft status, and instrument status.

The month of January for *MESSENGER* was marked by 43 website releases, 27 news releases, and a NASA news conference on January 30 (one day before the 50th anniversary of the historic flight of *Explorer 1*). By the end of the month, most science team members had returned to their home institutions. Since that time, the team members have been writing papers and giving presentations at meetings around the world to report the findings from the flyby. Equally important, the *MESSENGER* team has been preparing the command loads for the spacecraft's second Mercury flyby, in October.

What's Next?

We now know that Mercury is a more complex planet than had been appreciated even after *Mariner 10*, and the observations made in January have whetted the planetary science community's appetite for more. *MESSENGER's* October flyby will oblige, because the sunlit side of Mercury will be nearly the opposite of that viewed in January, and another 30 percent of the planet's surface will be seen at close range for the first time.

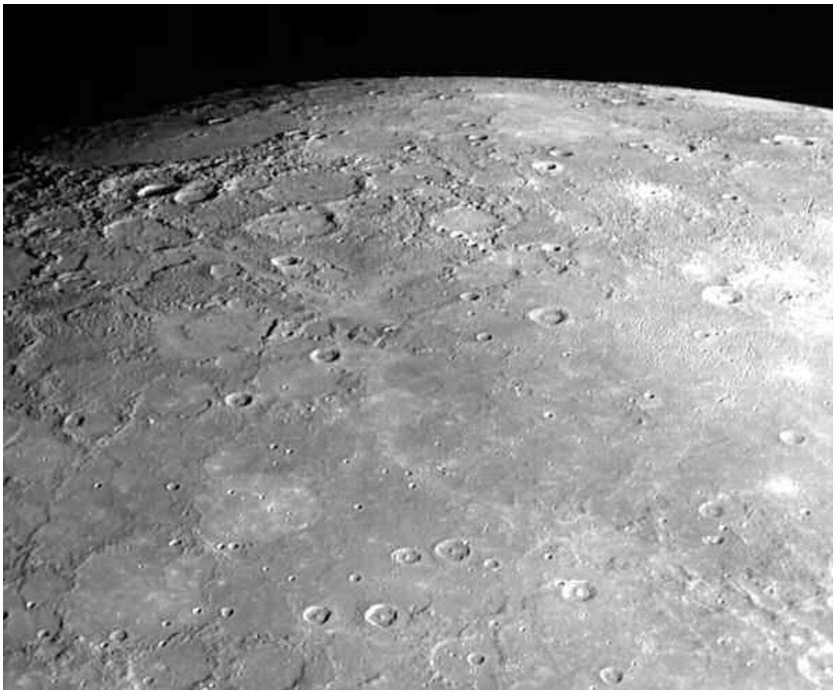
The journey to orbit insertion is barely more than half completed, and two more Mercury flybys promise to return data sets comparable in their impact to what was obtained in January. As of March 2011, *MESSENGER* is slated to be in a 12-hour orbit about Mercury, in effect making a diverse set of observations twice per day that will rival those of the entire January flyby. The innermost planet will be understudied no longer.

Where Is MESSENGER Now?

A quick look at the counters on the* MESSENGER *website gives a sense of milestones past and future. As of 6:27 p.m. EDT on July 25, 2008, the mission elapsed time was 1,452 days, 16 hours; the time to the second Mercury flyby was 72 days, 14 hours; the time to Mercury orbit insertion was 965 days, 11 hours; and the distance traveled was 2,674,631,351 miles.

Log on to* messenger.jhuapl.edu *to see where* MESSENGER *is now.

Ralph L. McNutt, Jr. is the MESSENGER *project scientist and a co-investigator on the science team; Sean C. Solomon is the* MESSENGER *principal investigator. Both began working on the initial* MESSENGER *concept in the spring of 1996 and have seen the mission through spacecraft and payload development and testing, launch, and—now—the first return of spacecraft observations from Mercury since 1975. McNutt is also a co-investigator on the* New Horizons *and* Voyager *missions and a member of the* Cassini *science team. Solomon is the director of the Department of Terrestrial Magnetism and principal investigator there for the Carnegie Institution's NASA Astrobiology Institute team. A veteran of the* Magellan *and* Mars Global Surveyor *missions, he is also a co-investigator on the lunar* GRAIL *mission, currently under development.*



In the more varied terrain toward the north pole, flooding of crater interiors by smooth plains material is visible, as are smaller, younger craters overlying the plains material. The images on these two pages were acquired by* MESSENGER*'s Narrow Angle Camera (NAC) at an outgoing distance of about 32,000 kilometers (20,000 miles). *Image: NASA/APL/CIW*