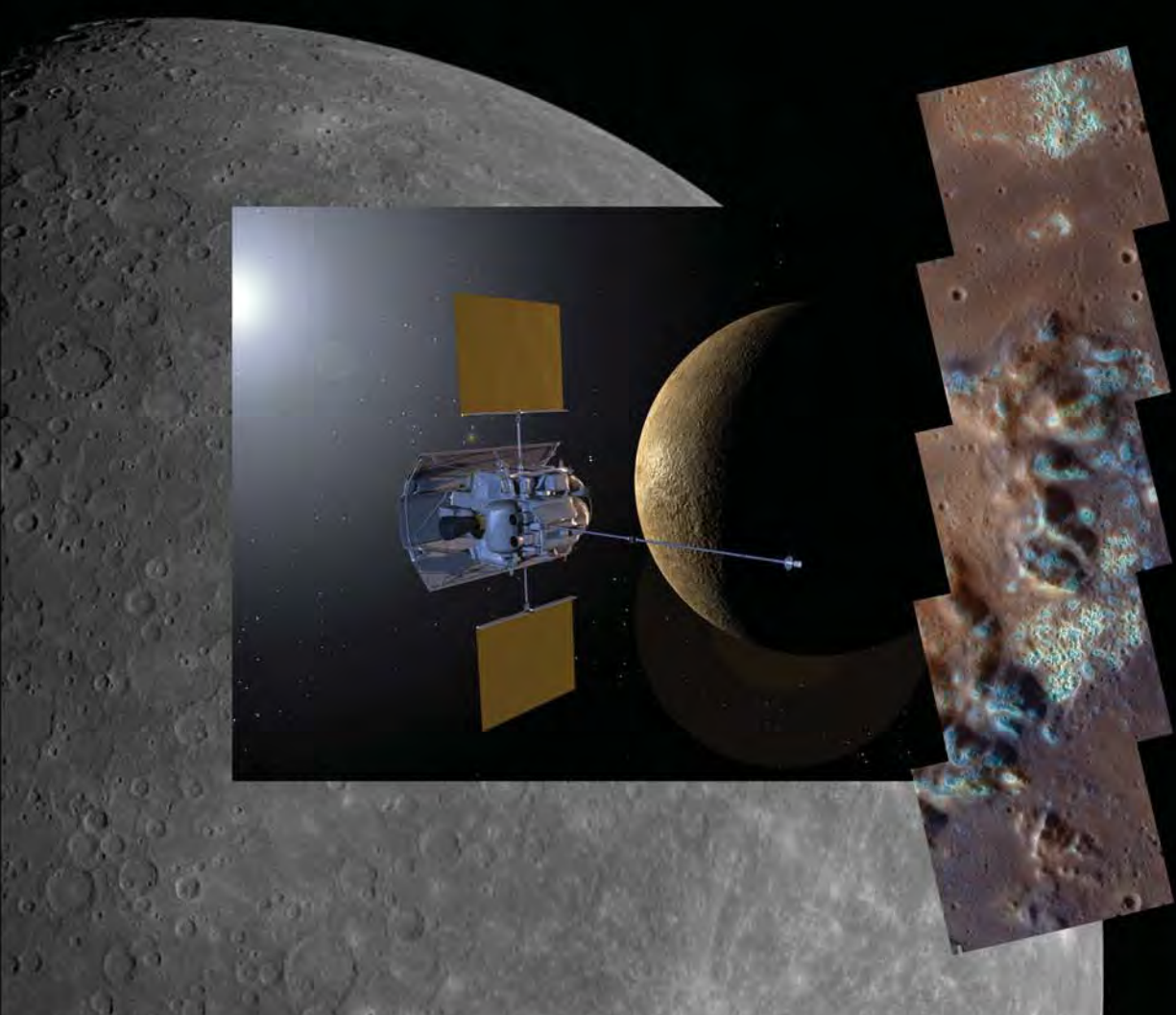


MESSENGER:

Revealing Mercury's Secrets



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MESSENGER: Revealing Mercury's Secrets

— *Brett Denevi and Carolyn Ernst, The Johns Hopkins University Applied Physics Laboratory*

The MErcury Surface, Space ENvironment, GEOchemistry, and Ranging (MESSENGER) spacecraft was placed into orbit around Mercury on March 18, 2011, less than one year ago, and our understanding of the innermost planet has already been transformed. Prior to MESSENGER's first looks, our knowledge was limited to snapshots in time: six flybys of the planet, three each by Mariner 10 and MESSENGER. Mariner 10 launched in 1973 and, after a gravity assist from Venus, sent back the first close-up data from Mercury in 1974 and 1975. Less than half of the planet was imaged, however, leaving huge gaps in our picture of how Mercury formed and evolved. There was tantalizing evidence for volcanism on the surface, but not enough to settle the debate over how the plains on Mercury formed. Huge tectonic features suggested contraction of the crust on a hemispherical scale, but the history of the other hemisphere was unknown. Very little was known about the composition of the surface, the internal structure of the planet, or why it is so dense.

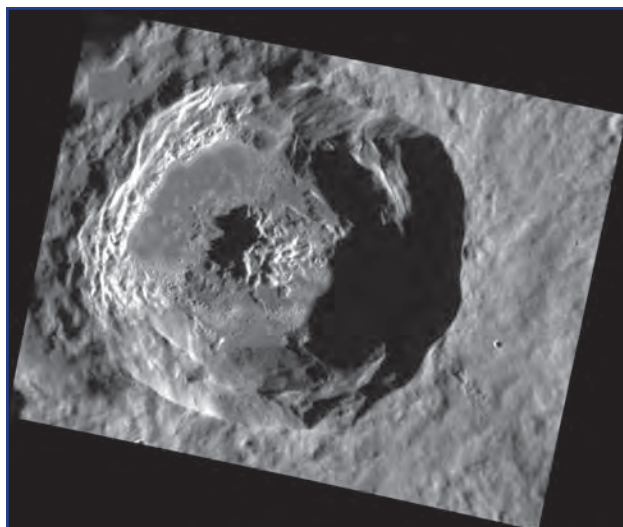
For over 30 years Mercury remained a mystery, with globes blank on one side and without the data to answer many of these basic questions. MESSENGER's flybys in 2008 and 2009 began to fill in the picture, providing the first images of the other side of the planet and finally allowing for global analyses. But not until MESSENGER's arrival in orbit did our view truly come into focus, revealing a unique and complex world. We now have the equivalent of two flybys every day. MESSENGER orbits Mercury once every 12 hours, coming as close as 200 kilometers from the surface in the northern hemisphere and swinging out to over 15,000 kilometers elevation in the south, allowing the spacecraft to cool down as it moves away from the hot dayside surface. This eccentric orbit means



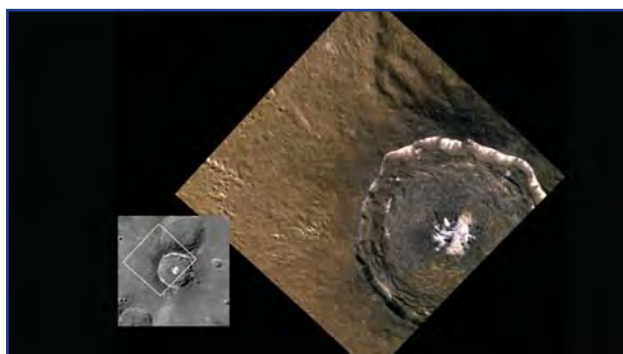
Schematic illustration of the operation of MESSENGER's Mercury Laser Altimeter (MLA). MLA ranges to Mercury whenever the spacecraft is within 1800 kilometers of the surface. Eight times per second, MLA's laser emits a short (5-nanosecond) pulse, which propagates along the laser transmitter's line of sight to the surface, where a fraction of the pulse energy is reflected from the surface and propagates back to MLA's four receiver telescopes. The time of flight of the laser pulse provides the distance to the portion of the surface from which the signal was reflected. Credit: NASA/The Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

that the Mercury Laser Altimeter (MLA) cannot observe much of the southern hemisphere, other instruments yield southern-hemisphere measurements that are large-scale averages, and the highest-resolution images will always be in the north. But even with these observational constraints, we can now begin to assess with confidence Mercury's significance as the innermost member of our terrestrial family.

Since MESSENGER entered orbit, the Mercury Dual Imaging System (MDIS) cameras have taken over 60,000 images covering over 99% of Mercury's surface, some at resolutions as good as 10 meters/pixel. Flyby imaging hinted at the existence of volcanic plains toward Mercury's north pole, but MESSENGER's global imaging has documented extensive volcanism across the planet, including an expanse of relatively young volcanic plains at high northern latitudes equal in area to nearly two-thirds the size of the continental United States. High-resolution



This stunning, and as of yet unnamed, crater lies within the Caloris basin. Its floor provides another example of the beautiful "hollows" found on Mercury and has an etched appearance similar to that found in other young craters (see also the front cover for a high-resolution view of Mercury's "hollows"). Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

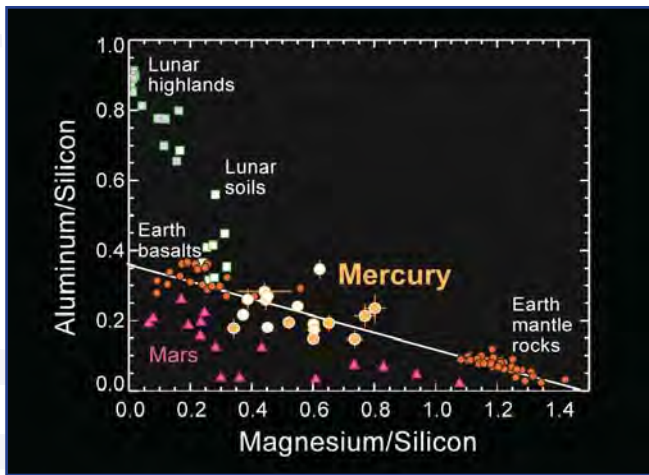


This spectacular view of the crater Degas was obtained as a high-resolution targeted observation (90 m/pixel). Impact melt coats its floor, and as the melt cooled and shrank, it formed the cracks observed across the crater. For context, Mariner 10's view of Degas is shown at left. Degas is 52 km in diameter and is centered at 37.1°N, 232.8°E. Credit: NASA/The Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

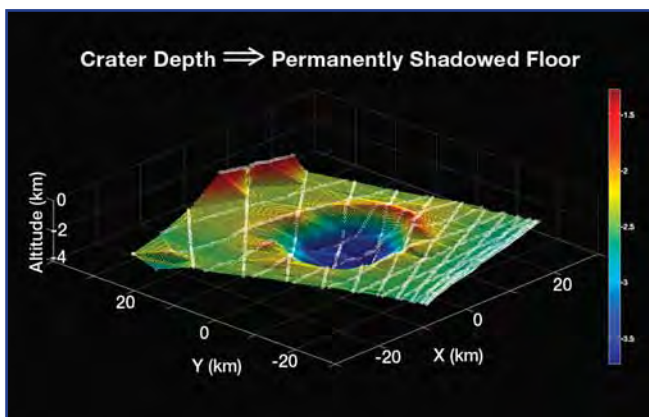
aluminum/silicon and calcium/silicon ratios and higher magnesium/silicon ratios. In this regard Mercury's crust is more similar in places to the lunar maria, but with two major differences: Surface abundances of iron and titanium are extremely low on Mercury. In other places Mercury's surface appears to be more similar to rocks formed from magmas that once erupted very early in Earth's history, the high-magnesium and low-silicon komatiites. Another surprise is the high abundance of sulfur detected on the surface, at least 10 times higher than found on surfaces of Earth or the Moon,

images have revealed "hollows," unexpected geologic landforms that may be among the youngest features on the surface. These hollows are shallow, irregular depressions often surrounded by bright halos and are found across the globe, usually associated with rocks excavated from depth by the crater-forming process (crater central peaks, peak rings, floors, and walls). One formation mechanism involves the loss of volatile material, possibly by sublimation. The hollows support the implication that Mercury's interior contains higher abundances of volatiles than previously thought — especially surprising given Mercury's proximity to the Sun. MESSENGER images confirmed the dominantly contractional deformation of Mercury's crust, with huge lobate scarps and associated fault systems having deformed the crust across the globe. An exciting discovery is the existence of dozens of areas of local extension, primarily within craters and basins, another indicator of Mercury's complex geologic history.

Some of the most intriguing new results are coming from the geochemical measurements made by MESSENGER's X-Ray Spectrometer (XRS) and Gamma-Ray Spectrometer (GRS). The prevailing paradigm for many years was that Mercury's crust was similar to the anorthositic lunar highlands and represented an early crust formed by plagioclase flotation in a global magma ocean. Images from MESSENGER's flybys suggested that the geology was actually quite different, with much of the crust having formed through volcanic eruptions. But the XRS and GRS observations from orbit have confirmed that Mercury is truly not the Moon: The crust has much lower



Major-element composition of Mercury's surface materials, depicted on the same graph, as measured by the MESSENGER XRS. Mercury has lower Al/Si and higher Mg/Si than typical lunar surface materials and terrestrial basalts, indicating a lower fraction of the common mineral plagioclase feldspar. Credit: NASA/The Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

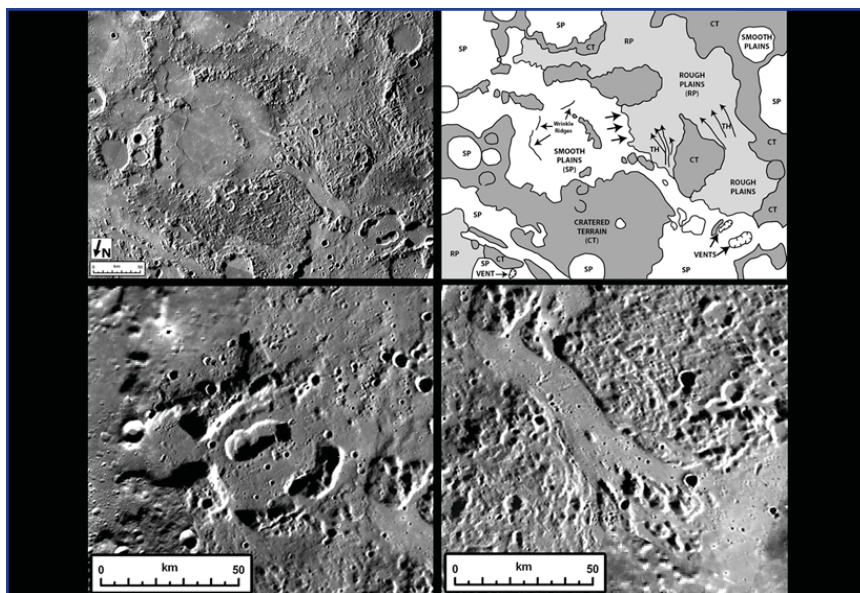


This topographic contour map was constructed from the several MLA profiles (lines of white circles) that pass through and near a prominent impact crater. The color scale at right is in kilometers, and north is at the four o'clock position. Calculations show that the topography of the crater is consistent with the prediction that the southernmost portion of the crater floor is in permanent shadow. Credit: NASA/The Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

which implies that Mercury formed in a highly reducing environment. The formation and early evolution of Mercury is also now informed by measurements of the surface abundances of radioactive elements from GRS. These data show that the abundance of the moderately volatile element potassium is as high relative to the refractory elements thorium and uranium as on Mars or Earth, suggesting that extreme and sustained heating such as from a giant impact or vaporization by an early hot solar nebula cannot account for Mercury's high density.

Mercury's geophysical story is also beginning to emerge. Topographic measurements from MLA show a planet with large long-wavelength topographic variations. A substantial lowlands that hosts the northern volcanic plains is on average 2 kilometers lower than the surrounding area but is not the result of any one basin-forming impact. The topography of Caloris basin has also been heavily modified since formation and interior plains emplacement, rendering it nearly unrecognizable on an elevation map. New results for Mercury's gravity field are also providing surprises. The Mariner 10 and MESSENGER flybys yielded different estimates for the value for C20, the polar flattening of the gravity field and an important quantity for understanding the nature of Mercury's core. Prior to orbit insertion, MESSENGER's Geophysics Discipline Group conducted a friendly pool to guess the correct value for C20. The winner: P.I. Sean Solomon (a close runner-up was NASA administrator Charles Bolden). The detailed work of interpreting the internal structure of Mercury is underway.

Although MESSENGER's primary mission will end on March 17, 2012, NASA recently announced that they would extend the mission by one Earth year, through March 17, 2013. The extended mission is designed to answer scientific questions that have arisen only after discoveries made from orbit: What are the sources of Mercury's surface volatiles? How recently was Mercury volcanically active?



Candidate volcanic vents, lava flow-related channels, and teardrop-shaped features. Upper left and right: Image and sketch map of the assemblage of volcanic flow-related features. Lower left: Pits interpreted as source vents. Lower right: Teardrop-shaped hills and channel interpreted to be formed by lava erosion. Credit: Courtesy of Science/AAAS.

How has the long-wavelength topography of the planet evolved? These questions will be pursued through continued collection of data from all of MESSENGER's instruments, including many more targeted observations and images. On the basis of the exciting results of the primary mission to date, Mercury has many more secrets waiting to be discovered!



About the Authors:

Carolyn Ernst (pictured left) is a Staff Scientist in the Space Department of The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland (APL). Her main research focuses on impact cratering, including such topics as experimental impact flash photometry, using crater ejecta to probe subsurface stratigraphy, and

small body crater morphology and modification. She is the primary sequencer for the Mercury Laser Altimeter (MLA) and also works on calibration and data analysis for the Mercury Dual Imaging System (MDIS), both onboard the MESSENGER spacecraft. She received her Ph.D. in geology from Brown University.

Brett W. Denevi (pictured right) is also a Staff Scientist in the Space Department of APL. Her research focuses on the composition, origin, and evolution of planetary and asteroidal surfaces, including topics such as regolith development, chemical and mineralogic composition of planetary materials as derived from ultraviolet, visible, and near-infrared spectroscopy, and geologic mapping of planetary surfaces. She has extensive experience in sensor calibration and image processing. She is currently working on the calibration and analysis of images from MESSENGER's Mercury Dual Imaging System (MDIS), and she is a Co-Investigator on the Lunar Reconnaissance Orbiter Camera and a Participating Scientist on the Dawn mission to Vesta. She received her Ph.D. in geology and geophysics from the University of Hawaii.