

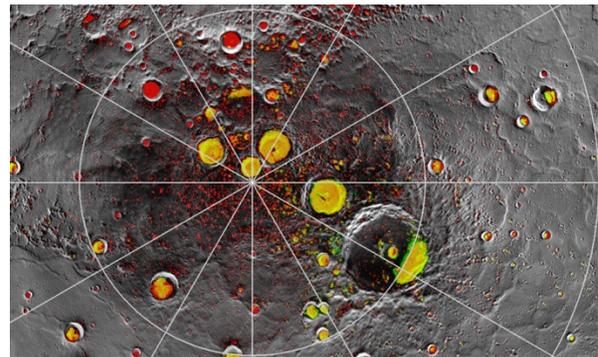
**FUTURE MERCURY EXPLORATION: UNIQUE SCIENCE OPPORTUNITIES FROM OUR SOLAR SYSTEM'S INNERMOST PLANET.** Nancy L. Chabot<sup>1</sup>, Ralph L. McNutt, Jr.<sup>1</sup>, David T. Blewett<sup>1</sup>, Brett W. Denevi<sup>1</sup>, Carolyn M. Ernst<sup>1</sup>, Erwan Mazarico<sup>2</sup>, Lauren M. Jozwiak<sup>1</sup> <sup>1</sup>Johns Hopkins Applied Physics Laboratory, Laurel MD 20723. (Nancy.Chabot@jhuapl.edu), <sup>2</sup>NASA Goddard Space Flight Center, Greenbelt, MD, 20771.

**The Need:** Mercury is one of only five terrestrial bodies (the four rocky planets and the Moon) in the inner Solar System, each of which is unique. Mercury represents an endmember of planetary formation: the planet closest to the Sun, with a highly reduced, but volatile-bearing surface, and an oversized metallic core in comparison to the other planets. A truly fundamental question in planetary science is: *What properties and processes make these terrestrial bodies form and evolve along different paths, resulting in the diverse bodies that we observe today?* The future scientific exploration of our Solar System must use all five bodies to make advances on this fundamental question. The implications are significant, not only for understanding our own Solar System but also for understanding Solar System formation and evolution in general and interpreting exoplanet systems. Any Planetary Science Vision must include Mercury exploration.

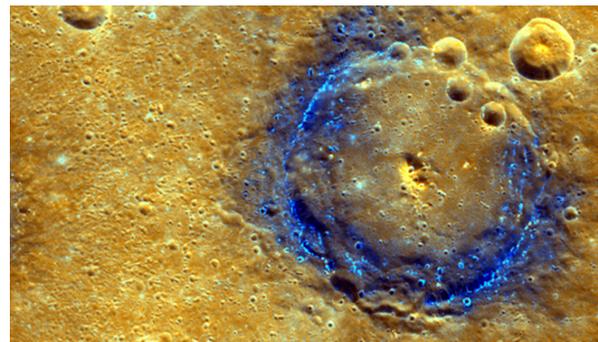
**The Present:** NASA's recently completed MErcury Surface, Space ENvironment, GEOchemistry, and Ranging (MESSENGER) mission was hugely successful, returning unprecedented data about Mercury [1]. The joint ESA-JAXA BepiColombo mission [2] is scheduled to launch shortly, carrying two orbiters to further advance knowledge of the space environment and surface science of the planet. Continued support for research investigations related to and motivated by these orbital datasets is critically important. With these orbital missions, the reconnaissance and initial exploration phases of investigating Mercury will have been completed [3], laying the foundation for the next phases of Mercury exploration.

**The Near Future – Landed Science:** The next step in Mercury exploration is to conduct *in situ* investigations on the surface. Though Mercury's proximity to the Sun means the surface reaches temperatures as high as 700K in daylight and can plunge to 100K at night, even with current technology, short-lived landers and rovers to do focused science on the surface are possible. Varied mission designs, from a sunshade, to a nighttime or shadowed landing site, to a radioisotope power supply, for instance, can overcome the challenges of Mercury's thermal environment. Future technological advancements to operate landers or rovers at even higher temperatures than currently envisioned would also extend mission lifetime and the science achieved, enabling very accurate knowledge of Mercury's orbital and rotational dynamics through radio tracking. Technology to equip landers with seis-

mic and heat flow instrumentation would provide crucial information about Mercury's internal structure, as would enhanced orbital gravity mapping. *In situ* age dating of any surface would establish key constraints on the chronology of Mercury's evolution. Launch vehicles larger than those of the Mariner 10 or MESSENGER missions could enable novel landed missions to Mercury, potentially even without the need for multiple gravity assists. Mercury is an evolved planet and consequently has a diversity of surface regions each with compelling science questions. Examples of high-science-return landed science locations, not in priority order, include:

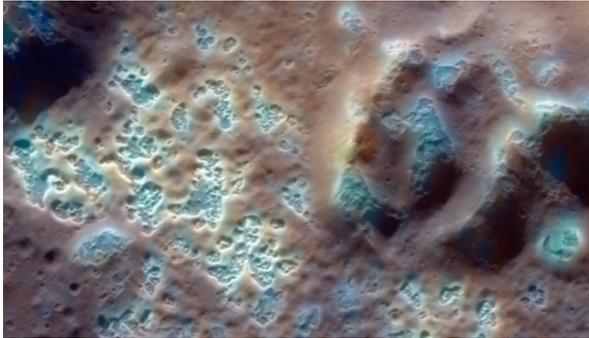


**Polar Deposits.** Extensive water-ice deposits are contained in the permanently shadowed regions near Mercury's poles, hypothesized to be covered by organic-rich volatiles. A landed science mission would determine the composition, distribution, and physical properties of these deposits, answering key questions about the delivery, evolution, and retention of water and organics to the terrestrial planets, with comparisons to lunar polar cold traps and potential implications for early Earth. [e.g., 4, 5]



**Low-Reflectance Material.** Mercury's carbon-rich low-reflectance material appears to stem from Mercu-

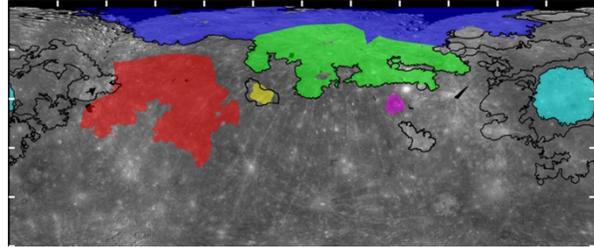
ry's ancient crust, providing unique insight into the early stages of planetary evolution. A landed science mission would determine the mineralogical nature and elemental makeup of this material, testing models of early crust formation on Mercury and the processes of early crustal formation in general, which are not preserved on Venus and Earth. [e.g., 6]



**Hollows.** Discovered by MESSENGER, hollows are enigmatic landforms that appear to be extremely young and unique to Mercury, potentially forming in the present day. A landed mission would determine crucial information on the composition, physical properties, and the processes that formed hollows. This information would provide insight into the roles played by volatile elements in Mercury's crust and the relative importance of solar heating, micrometeoroid impact, and ion bombardment in the extreme form of space weathering that occurs on Mercury. [e.g., 7, 8]



**Volcanic Features.** Mercury's surface has been heavily shaped by volcanism, with extensive smooth volcanic plains and explosive volcanic vents distributed across the surface. A landed mission would determine the elemental and mineralogical composition of these volcanic features, providing new insight into the nature of Mercury's magma source regions and key constraints for thermal models of the interior and the timing of volcanism in relation to Mercury's global contraction. [e.g., 9, 10]



**Geochemical Terranes.** Mercury's surface shows evidence for distinct geochemical terranes, each with unique elemental compositions. A landed mission to a given terrane would determine the distinct mineralogical and chemical characteristics of the terrane, enabling a new understanding of how the terranes relate to each other and the extent to which mantle chemical heterogeneities or large impact events shaped the formation and evolution of the terranes. [e.g., 11]

**The Distant Future – Multiple Landed Missions and Sample Return:** From the preceding section, it is clear that a single lander or rover, equipped with *in situ* measurement capabilities, to any of these locations would address compelling science on its own, and is the next logical step in Mercury exploration. However, as at Mars, a single lander or rover cannot answer all of Mercury's highest level science questions. Technologies to support multiple landed missions, to multiple diverse surface locations, would be a game-changing advancement for Mercury exploration. Networked small landers or rovers communicating with a larger orbiter that would collect and relay the data back to Earth would enable the *in situ* exploration of multiple surface locations on Mercury.

Ultimately, sample return is key. The advanced analytical techniques in Earth-based laboratories always have, and will, surpass capabilities of *in situ* landed measurements. Advances in sample return capabilities, such as the technologies and architectures being developed for Mars, would enable samples returned from any Solar System body, including Mercury. High-performance launch vehicles could, with appropriate investment, enable Mercury sample return by 2050.

**References:** [1] Solomon et al. (2011) *Planet. Space Sci.* 59, 1827-1828. [2] Benkhoff et al. (2010) *Plant. Space Sci.* 58, 2-20. [3] Wasserburg et al. (1978) *Nat. Acad. Sci.*, 53 pp. [4] Lawrence et al., (2013) *Science* 339, 292-296. [5] Chabot et al. (2016) *GRL* 43, 9461-9468. [6] Peplowski et al. (2016) *Nature Geoscience* 9, 273-276. [7] Blewett et al. (2013) *JGR* 118, 1013-1032. [8] Blewett et al. (2016) *JGR* 121, 1798-1813. [9] Head et al. (2009) *EPSL* 285, 227-242. [10] Thomas et al., (2015) *EPSL* 431, 164-172. [11] Weider et al. (2015) *EPSL* 416, 109-120.