MESSENGER'S SECOND EXTENDED MISSION: EXPLORING MERCURY’S DYNAMIC MAGNETOSPHERE AND COMPLEX SURFACE AT UNPRECEDEDENT SCALES. Louise M. Prockter1, Scott L. Murchie1, Sean C. Solomon2,3, Larry R. Nittler4, Ralph L. McNutt, Jr.1, Nancy L. Chabot5, David J. Lawrence1, Larry G. Evans4, Catherine L. Johnson1,6, Roger J. Phillips1, Ronald J. Vervack, Jr.1, Haje Korth1, Mark E. Perry1, Peter D. Bedini1, and Helene L. Winters1. 1The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA (louise.prockter@jhuapl.edu); 2Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC, 20015, USA; 3Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA; 4NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA; 5Department of Earth, Ocean, and Atmospheric Sciences, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada; 6Planetary Science Institute, Tucson, AZ, 85719, USA; 7Planetary Science Directorate, Southwest Research Institute, Boulder, CO, 80302, USA.

Summary. The MERCURY Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER) mission is set to begin a second Extended Mission in March 2013 that will provide new observations of Mercury’s surface and interior at unprecedented spatial resolution and of the planet’s dynamic magnetosphere and exosphere at high time resolution during the peak and declining phase of the current solar cycle.

MESSENGER's Payload. On 18 March 2011, MESSENGER became the first spacecraft to orbit Mercury. The planet's interior, surface, exosphere, and magnetosphere are being studied by eight science investigations: the Mercury Dual Imaging System (MDIS); the Gamma-Ray and Neutron Spectrometer (GRNS); the X-Ray Spectrometer (XRS); a Magnetometer (MAG); the Mercury Laser Altimeter (MLA); the Mercury Atmospheric and Surface Composition Spectrometer (MASCS); the Energetic Particle and Plasma Spectrometer (EPPS); and a Radio Science (RS) investigation [1].

Primary Mission. During the one-Earth-year Primary Mission, six high-level questions were investigated: (a) the origin of Mercury’s high metal/silicate ratio; (b) the geologic history of the planet; (c) the nature of the planetary magnetic field; (d) the structure of the core; (e) the nature of Mercury’s unusual polar deposits; and (f) the inventory of volatiles on and near Mercury. These objectives were addressed through cross-cutting global measurement campaigns: maps of elemental compositions (GRNS, XRS); global photomosaics and spectral measurements to map morphology and spectral variations (MDIS, MASCS); high-precision topographic mapping of the northern hemisphere (MLA); determination of a multipole magnetic field model (MAG); determination of the global gravity field and moments of inertia (RS and MLA); determination of the nature of the radar-bright polar deposits (GRNS, MLA); and characterization of exospheric and magnetospheric species as functions of local time, heliocentric distance, and solar activity (MASCS, EPPS). Key findings include that the planet is pervasively covered by volcanic plains [e.g., 2]; that the surface and, by inference, the crust are low in Fe, include compositions intermediate between basalt and komatiite, and are rich in S [e.g., 3]; that surface topography has been subject to continuing long-wavelength deformation [e.g., 4]; that extensional deformation is common within large impact structures [e.g., 5]; that the magnetic field is dominantly dipolar, but the dipole is offset northward from the center of the planet by ~480 km [6]; that the core is over 2000 km in radius and may include Si as well as S [e.g., 7]; that polar deposits areconfined to permanently shadowed areas [8] and consist of water ice and an unusually dark, possibly organic-rich material [9-11]; that pyroclastic volcanism was important [12]; that ablation of a volatile species is producing karst-like "hollows" [13]; that spatially localized density enhancements in the exosphere exist for the three major species Na, Ca, and Mg [e.g., 14]; and that bursts of energetic (> 100 keV) electrons occur in Mercury’s magnetosphere [15]. MESSENGER completed its Primary Mission in March 2012, with sufficient propellant to continue operations.

First Extended Mission. These discoveries raised questions that could not have been anticipated prior to MESSENGER: (a) the sources of surface volatiles; (b) the duration of volcanism; (c) the evolution of long-wavelength topography with time; (d) the origin of localized regions of enhanced exospheric density; (e) the effect of the solar cycle on Mercury’s exosphere; and (f) the origin of Mercury’s energetic electrons. These questions are being addressed with twelve new measurement campaigns over during a first Extended Mission (XM1) that began in March 2012 and ends in March 2013. Only three campaigns are global (higher-resolution color mapping, and complementary global mapping of morphology at different illumination conditions). The remaining campaigns include higher-resolution measurements of specific targets (e.g., MDIS images at pyroclastic vents, hollows, and young volcanic features; MLA profiles of topographic and tectonic features; MASCS spectra of hollows) or are phased in time and space to characterize dynamic phenomena. For example, the exosphere is being measured repeatedly at key locations by MASCS and EPPS to characterize variations on timescales from hours to Mercury years.
Second Extended Mission. Six new questions have been stimulated by the Primary Mission and XM1 findings, and coherent investigations have been designed to address them. The new observing campaigns could not be accommodated within the full schedule of XM1. Implementation of those campaigns is planned to begin in March 2013 in a second Extended Mission (XM2). The new questions include the following:

(1) What active and recent processes have affected Mercury’s surface? Observations indicate that the hollows are actively forming and that initiation of hollow formation may be related to exposure at the surface. However, neither the relation to mass wasting nor the potential contribution to exospheric volatiles is understood. In addition, there is poor understanding of processes by which optical properties of freshly exposed crustal materials are modified in the space environment. These processes will be investigated through a campaign of MDIS high-resolution stereo and color images and MASCS and EPPS measurements over hollows.

(2) How has contractional deformation evolved over time? Orbital imaging and altimetry show that global contraction has been manifested in a diverse range of landforms. Key unresolved issues include how major systems of lobate scarps developed and whether they are associated with fold-and-thrust belts, as well as how contractional deformation has changed over time and how recently such deformation has been active. These questions will be addressed with MDIS targeted high-resolution stereo and MLA measurements.

(3) How have compositions of volcanic materials evolved over time? Determining the prevalence and forms of volcanism were among the objectives of the primary mission and XM1. However, the variation of magma composition over Mercury’s history is not yet clear. Compositions of surface volcanic materials, their relationship to depths and extents of partial melting, and compositional comparisons between surface volcanic units and material excavated from depth will provide fresh insight into the links between volcanism and the thermal and dynamical history of Mercury’s mantle. These issues will be investigated through a campaign of targeted MDIS 11-color images, 5-color MDIS mapping of the northern plains, and targeted MASCS and XRS measurements.

(4) What are the characteristics of volatile sequestration in the north polar region? The findings that radar-bright deposits correspond to permanently shadowed regions of craters, and that both water ice and dark material are present, motivate campaigns of MDIS imaging and MLA ranging and reflectance observations to understand physical processes governing the different frozen volatiles at Mercury’s poles.

(5) What are the consequences of precipitating ions and energetic electrons at Mercury? This question follows from the discovery of energetic electron bursts [15]; X-ray fluorescence from the nightside surface, presumably in response to particle precipitation [16]; and dense magnetospheric cusps hosting energetic heavy ions [17]. Energetic particle bombardment of the surface may contribute to space weathering, and sputtering may also be a prominent source process for the exosphere. The influence of charged-particle bombardment will be quantified by combining tailored EPPS and GRNS observations of plasma, flows, and energetic particles with MASCS and XRS measurements of surface and exospheric response.

(6) How do the exosphere and magnetosphere respond to extreme conditions near solar maximum? Orbital observations indicate that solar wind interactions with Mercury’s magnetic field are even more dynamic and disturbed than anticipated. XM2 will span solar maximum and the onset of the declining phase of the current solar cycle, a time of greatest solar flare activity and novel forms of solar disturbances. The effects of expected evolution in solar behavior should be qualitatively different from those observed to date and will be monitored with MAG, EPPS, and MASCS.