MESSENGER AT MERCURY: FLYBY ACCOMPLISHMENTS AND ORBITAL OBSERVING PLANS.
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Introduction: The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, launched in August 2004 under NASA's Discovery Program, is scheduled to be inserted into orbit about the planet Mercury in March 2011. MESSENGER's three flybys of Mercury in 2008-09 marked the first spacecraft visits to the innermost planet since those of Mariner 10 in 1974-1975 [1]. Here we give a summary of the discoveries made during MESSENGER's Mercury flybys and an overview of the year-long observations planned from orbit.

Discoveries from the Mercury Flybys: In addition to providing key gravity assists that enable orbit insertion as well as opportunities to test scientific operations and command sequences for all payload instruments, MESSENGER's three flybys of Mercury yielded a number of discoveries that have markedly changed our view of Mercury and influenced our preparations for orbital operations. For Mercury's geological history, MESSENGER established that:

• Volcanism was widespread on Mercury and extended from before the end of heavy bombardment to the second half of solar system history [2-5].

• Mercury experienced pyroclastic volcanism, indicating that interior volatile contents were at least locally much higher than thought [2,6].

• Impact crater formation excavated material compositionally distinct from surrounding terrain, providing a means to probe composition versus depth [7-9].

• Contraction spanned much of Mercury's geologic history [10-12].

• Large impact basins on Mercury were foci for concentrated magmatic activity and diverse styles of deformation [5,13,14].

On the composition of Mercury's surface and surface-derived exosphere, MESSENGER showed that:

• Mercury's surface silicates contain little or no FeO [15,16].

• Mercury's thermal neutron flux matches that of several lunar maria, indicating that Fe and Ti are present in comparable collective abundances, perhaps as oxides [17].

• Mg and Ca^+ are present in Mercury's exosphere [18,19].

• Mercury's comet-like neutral tail contains multiple species [18-20].

• Mg, Ca, and Na have distinct distributions in the exosphere and tail, indicating a different mix of time-variable source, transfer, and loss processes [18-21].

Regarding Mercury's internal structure and dynamics, MESSENGER demonstrated that:

• The equatorial topographic relief of Mercury is at least 5.5 km [22].

• Mercury's long-wavelength equatorial topography is well fit by an ellipse aligned with the equatorial ellipticity of the gravity field [23].

• The case for a liquid outer core on Mercury is greatly strengthened [23].

• Mercury's internal magnetic field is dominantly dipolar with a vector moment closely aligned with the spin axis [24-26].

Regarding Mercury's magnetospheric dynamics, MESSENGER has established that:

• Mercury's magnetosphere is more responsive to interplanetary magnetic field (IMF) fluctuations than those of other planets [27-29].

• Under southward IMF, rates of magnetic reconnection are ~10 times that typical at Earth [28].

• Loading of magnetic flux from the dayside magnetosphere to the magnetotail and substorm-like unloading occur at timescales (minutes) much shorter than at Earth (hours), but no energetic particles have been observed to date [29].

• Loading can be so intense that much of Mercury's dayside could be exposed to the shocked solar wind of the magnetosheath during such episodes [29].

Plans for Orbital Operations: The scientific questions that underpin the MESSENGER mission led to a set of mission measurement requirements to be achieved by the seven payload instruments and the radio science experiment [1]. Interweaving the full set of observations in a manner that maximizes the opportunity to satisfy all mission requirements and yet meet all spacecraft pointing and thermal constraints was a complex optimization problem that was solved with a software tool (SciBox) that simulates science observations and tracks progress toward meeting each objective [30]. The final orbital observation plan, as the outcome of that optimization process, contains a number of elements.

MESSENGER's Mercury Dual Imaging System (MDIS) [31] will acquire a global monochrome image mosaic at better than 90% coverage and 250 m/pixel or better sampling, a global color image mosaic at better than 90% coverage and 1 km/pixel or better sampling, and global stereo imaging at better than 80% coverage and 250 m/pixel or better sampling. Higher-resolution images will be obtained of pre-selected targeted areas.

MESSENGER's elemental remote sensing instruments, including the Gamma-Ray and Neutron Spectrometer (GRNS) [32] and X-Ray Spectrometer (XRS) [33], will be operated nearly continuously and, although generally photon and neutron-count limited, will ascertain the average abundances of most major and some trace elements (O, Si, Mg, Fe, Ca, Al, Ti, S, H, K, U, Th) and obtain higher-resolution maps of Mercury's northern hemisphere and, for XRS, during times of high-intensity solar X-ray flux.

The Visible and Infrared Spectrograph (VIRS) channel of MESSENGER's Mercury Atmospheric and Surface Composition Spectrometer (MASCS) [34] will acquire global observations of spectral reflectance from 300 to 1450 nm. Targeted areas have been selected for coverage by the Ultraviolet and Visible Spectrometer (UVVS) channel of MASCS s well as by VIRS. In addition, MDIS and MASCS measurements at a range of photometric angles will support photometric corrections.

Observations of Mercury's exosphere with the UVVS channel of MASCS will include dayside radial limb profiles to provide full local-time coverage and probe important dusk-dawn asymmetries, polar scans over both poles during each dawn-dusk orbital season, mapping scans at high altitudes to provide spatial coverage on the day and night sides, and ride-along opportunities for further measurements.

MESSENGER's Mercury Laser Altimeter (MLA) [35] will acquire topographic profiles when the spacecraft altitude is 1800 km or less and will control spacecraft pointing at altitudes less than 1500 km; altimetric coverage will encompass the northern hemisphere, including the north polar region, and near-equatorial portions of the southern hemisphere. Topography over most of the southern hemisphere will be derived from stereo imaging, radio occultations, and limb profiles.

MESSENGER's radio science experiment [36] will ascertain Mercury's gravity field from Doppler signals during one 8-hour downlink per day with the spacecraft's high-gain antenna, during one of every two periapsis passes per day with the low-gain antenna, and during the second daily periapsis pass as geometry and transmitted signal strength permit.

MESSENGER's Magnetometer (MAG) [37] will measure the vector magnetic field at the highest instrument sampling rate (20 samples/s) for as much of every magnetospheric transit as possible, and when continuous high-rate sampling is not possible will operate in a triggered burst mode to capture magnetospheric boundaries at the highest sampling rate.

During each spacecraft orbit, the Energetic Particle Spectrometer (EPS) on MESSENGER's Energetic Particle and Plasma Spectrometer (EPPS) [38] will measure energetic electrons and ions, and the Fast Imaging Plasma Spectrometer (FIPS) will measure the energies and mass per charge of thermal plasma components, both within Mercury's magnetosphere and in Mercury's solar wind environment.

References: [1] S. C. Solomon et al. (2007) *Space Sci. Rev., 131,* 3-39. [2] J. W. Head et al. (2008) *Science, 321*, 69-72. [3] R. G. Strom et al. (2008) *Science, 321*, 79-81. [4] C. I. Fassett et al. (2009) *EPSL, 285*, 297-308. [5] L. M. Prockter et al. (2010) *Science, 329*, 668-671. [6] L. Kerber et al. (2009) *EPSL, 285*, 263-271. [7] M. S. Robinson et al. (2008) *Science, 321*, 66-69. [8] B. W. Denevi et al. (2009) *Science, 324*, 613-618. [9] C. M. Ernst et al. (2009) *Icarus*, *209*, 210-233. [10] S. C. Solomon et al. (2008) *Science, 321*, 59-62. [11] T. R. Watters et al. (2009) *EPSL, 285*, 283-296. [12] M. T. Zuber et al. (2010) *Icarus, 209*, 247-255. [13] S. L. Murchie et al. (2008) *Science, 321*, 73-76. [14] T. R. Watters et al. (2009) *Science, 324*, 618-621. [15] W. E. McClintock et al. (2008) *Science, 321*, 62-65. [16] G. M. Holsclaw et al. (2010) *Icarus, 209*, 179-194. [17] D. J. Lawrence et al. (2010) *Icarus*, *209*, 195-209. [18] W. E. McClintock et al. (2009) *Science, 324*, 610-613. [19] R. J. Vervack et al. (2010) *Science, 329*, 672-675. [20] W. E. McClintock et al. (2008) *Science, 321*, 92-94. [21] R. M. Killen et al. (2010) *Icarus, 209*, 75-87. [22] M. T. Zuber et al. (2008) *Science, 321*, 77-79. [23] D. E. Smith et al. (2010) *Icarus, 209*, 88-100. [24] B. J. Anderson et al. (2008) *Science, 321*, 82-85. [25] H. Uno et al. (2009) *EPSL, 285*, 328-339. [26] B. J. Anderson et al. (2009) *Space Sci. Rev.*, *152*, 307-339. [27] J. A. Slavin et al. (2008) *Science, 321*, 85-89. [28] J. A. Slavin et al. (2009) *Science, 324*, 606-610. [29] J. A. Slavin et al. (2010) *Science, 329*, 665-668. [30] B. J. Anderson et al. (2011) *Lunar Planet. Sci*., this volume. [31] S. E. Hawkins, III, et al. (2007) *Space Sci. Rev., 131,* 247-338. [32] J. O. Goldsten et al. (2007) *Space Sci. Rev.*, *131*, 339-391. [33] C. E. Schlemm, II, et al. (2007) *Space Sci. Rev., 131*, 393-415. [34] W. E. McClintock and M. R. Lankton (2007) *Space Sci. Rev.*, *131*, 481-522. [35] J. F. Cavanaugh et al. (2007) *Space Sci. Rev.*, *131*, 451-480. [36] D. K. Srinivasan et al. (2007) *Space Sci. Rev., 131*, 557-571. [37] B. J. Anderson et al. (2007) *Space Sci. Rev.*, *131*, 417-450. [38] G. B. Andrews et al. (2007) *Space Sci. Rev.*, *131*, 523-556.