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MESSENGER'S first and second flybys of Mercury: A scientific overview

Sean C. Solomon (1), Ralph L. McNutt, Jr., Brian J. Anderson, Deborah L. Domingue (2), Larry G. Evans (3), Robert E. Gold (2), James W. Head (4), Stamatios M. Krimigis (2,5), Scott L. Murchie (2), Larry R. Nittler (1), Roger J. Phillips (6), James A. Slavin (7), and Maria T. Zuber (8)

(1) Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA (scs@dtm.ciw.edu), (2) Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA, (3) Computer Sciences Corporation, Lanham-Seabrook, MD 20706, USA, (4) Department of Geological Sciences, Brown University, Providence, RI 02912, USA, (5) Academy of Athens, Athens 11527, Greece, (6) Southwest Research Institute, Boulder, CO 80302, USA, (7) Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA, (8) Department of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02129, USA.

Introduction

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, under NASA's Discovery Program, will be the first probe to orbit the planet Mercury. Launched in August 2004, MESSENGER has completed more than 70% of a complex interplanetary cruise phase that involves six planetary flybys. The first of three flybys of Mercury occurred on 14 January 2008, an event that marked the first spacecraft visit to the innermost planet since Mariner 10 last did so nearly 33 years ago. MESSENGER's second flyby of Mercury was on 6 October 2008, and a third will occur on 29 September 2009. The spacecraft will be inserted into orbit about Mercury on 18 March 2011. Here we give an overview of the observations made during the first two flybys and their scientific implications for Mercury.

MESSENGER Objectives and Payload

The MESSENGER mission [1] was designed to answer six questions: (1) What planetary formational processes led to Mercury's high ratio of metal to silicate? (2) What is the geological history of Mercury? (3) What are the nature and origin of Mercury's magnetic field? (4) What are the structure and state of Mercury's core? (5) What are the radar-reflective materials at Mercury's poles? (6) What are the important volatile species and their sources and sinks near Mercury?

Those questions, of broad importance to all the inner planets, led to the mission scientific objectives: to map globally the major element chemistry and mineralogy of the planet's surface; to image globally the surface at a horizontal resolution of hundreds of meters and make spectral measurements of major geologic units at visible and near-infrared wavelengths; to measure the vector magnetic field both near the planet and throughout the planet's magnetosphere; to measure Mercury's obliquity, the amplitude of Mercury's physical libration, and Mercury's long-wavelength gravity field; to carry out geochemical remote sensing of Mercury's polar surface and exosphere; and to assay the major neutral species in the exosphere and major charged species in the magnetosphere [1].

The measurement objectives for MESSENGER are met by a payload consisting of seven instruments plus radio science. These instruments are the Mercury Dual Imaging System (MDIS) [2], the Gamma-Ray and Neutron Spectrometer (GRNS) [3], the X-Ray Spectrometer (XRS) [4], the Magnetometer (MAG) [5], the Mercury Laser Altimeter (MLA) [6], the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) [7], and the Energetic Particle and Plasma Spectrometer (EPPS) [8].

Flyby Geometries

Each MESSENGER encounter of Mercury involves a nightside approach nearly in the planet's equatorial plane, and each is followed by a propulsive maneuver near the next aphelion to reduce the arrival speed at Mercury to the point that orbit insertion can be accomplished at the fourth encounter [9]. For the first two flybys, MESSENGER crossed the dawn terminator shortly after achieving a closest approach altitude of about 200 km (Fig. 1). During the first flyby MESSENGER viewed about 20% of Mercury's surface not seen by Mariner 10. Because MESSENGER's second Mercury flyby occurred approximately 1.5 Mercury solar days after the first, the opposite hemisphere was sunlit, and MESSENGER viewed another 30% of the surface from close range for the first time.

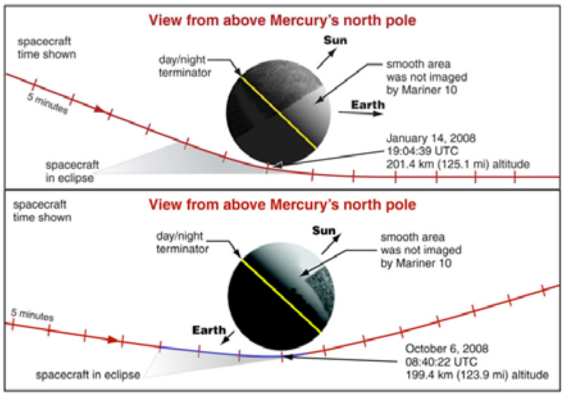

Figure 1: Geometry of MESSENGER's first two flybys of Mercury on 14 January and 6 October 2008.

Overview of Flyby Observations

Objectives of MESSENGER'S first two Mercury flybys included color imaging of the surface, the first high-resolution spectral reflectance measurements (from ultraviolet to near-infrared wavelengths) of surface composition, the first spacecraft altimetric measurements of surface topography, the first measurements of the abundances and compositions of plasma ions in Mercury's magnetosphere, the deepest penetrations yet into Mercury's magnetosphere, and searches for previously undetected species in Mercury's surface-based exosphere and neutral sodium tail. MESSENGER's first flyby confirmed that Mercury's internal magnetic field is primarily dipolar [10], documented water-group and other ions in the magnetosphere [11], mapped a north-south asymmetry in the planet's Na tail and determined the Na/Ca ratio near the tail and near the dawn terminator [12], and detected two outbound current-sheet boundaries that may indicate a planetary ion boundary layer [13], but did not observe energetic magnetospheric electrons as reported by Mariner 10 [13]. The laser altimeter demonstrated that the equatorial topographic relief of Mercury is at least 5 km [14], and no crustal magnetic anomalies were seen associated with features visible in images or altimetry [15].

MESSENGER's images from the first flyby provided evidence for widespread volcanism [16], and candidate sites for volcanic centers were identified [16, 17]. Also revealed were newly imaged lobate scarps and other tectonic landforms supportive of the hypothesis that Mercury contracted globally in response to interior cooling and growth of a solid inner core [18, 19]. The ~1500-km-diameter Caloris basin, viewed in its entirety for the first time by MESSENGER, was shown to be the focus for concentrations of volcanic centers [17], some displaying evidence of pyroclastic deposits [16]; smooth plains interior and exterior to the basin that are clearly younger than the basin-forming event [20]; and widespread contractional and extensional deformation [18, 19, 21]. Reflectance spectra of Mercury's surface showed no evidence for FeO in surface silicates [22]. The reflectance and color imaging observations provided fresh support for earlier inferences that Mercury's surface material consists dominantly of iron-poor, calcium-magnesium silicates with an admixture of spectrally neutral opaque minerals [23, 24].

During the second Mercury flyby in October, MESSENGER revealed the presence of neutral Mg in Mercury's anti-sunward tail and documented strongly differing distributions of Mg, Ca, and Na in the tail and the near-planet nightside exosphere, the result of different combinations of time-variable source, transfer, and loss processes [25]. A southward interplanetary magnetic field (IMF) during MESSENGER's second flyby was accompanied by multiple indications of magnetic reconnection at rates ~10 times typical at Earth [26]; in combination with the more quiescent conditions under northward IMF seen during the first flyby [13], the results indicate that Mercury's magnetosphere is more responsive to IMF direction than those of other planets [26]. The nearly global observations of Mercury surface units distinguishable by color and composition enforce the importance of the largely volcanic smooth plains, which occupy ~40% of the surface area, and of low-reflectance material [23], largely in deposits excavated by impact, occupying ~15% of surface area, and consistent with having formed within the crust or upper mantle [27]. The second flyby also revealed the ~700-km-diameter

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Rembrandt basin, less volcanically infilled than Caloris, but like Caloris a focus for concentrated magmatic and deformational activity [28].

Mission Prognosis

Although the trajectory of MESSENGER's third flyby of Mercury will be very similar to that for the second flyby, targeted observations of the surface and exosphere will provide new results. After insertion into an elliptical, nearly polar, 12-hour orbit about Mercury, MESSENGER will acquire global observations of the innermost planet and its environment for at least one Earth year.

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