MESSENGER'S EXTENDED MISSION. Ralph L. McNutt, Jr.[1], Sean C. Solomon[2], Brian J. Anderson[1], David T. Blewett[1], Larry G. Evans[3], Robert E. Gold[1], Scott L. Murchie[1], Larry R. Nittler[2], Roger J. Phillips[4], Louise M. Prockter[1], James A. Slavin[5], Ronald J. Vervack, Jr.[1], Maria T. Zuber[6], and the MESSENGER Team, [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA (ralph.mcnutt@jhuapl.edu); [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [3]Computer Sciences Corporation, Lanham-Seabrook, MD 20706, USA; [4]Southwest Research Institute, Boulder, CO 80302, USA; [5]Department of Atmospheric, Oceanic and Space Sciences, The University of Michigan, Ann Arbor, MI 48109, USA; [6]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, is the first probe to orbit the planet Mercury. Launched in August 2004, MESSENGER's three flybys of Mercury marked the first spacecraft visits to the innermost planet since those of Mariner 10 in 1974-1975 [1]. Following a successful orbit insertion on 18 March 2011, MESSENGER has been gathering data successfully during its primary, one-Earth-year-long mission. Following a proposal to NASA for an extended science mission in Mercury orbit, such a mission for an additional Earth year of operations was approved and announced on 9 November 2011. Here we give an overview of the extended-mission science questions posed from prime-mission results to date and the plans for carrying out the required observations to address these new questions.

Extended Mission Science Questions and Measurement Objectives: Building on the scientific results to date from the primary mission, six new – more focused – science questions have been posed for the extended mission: (1) What are the sources of surface volatiles? (2) How late into Mercury's history did volcanism persist? (3) How did Mercury's long-wavelength topography change with time? (4) What is the origin of localized regions of enhanced exospheric density? (5) How does the solar cycle affect Mercury's exosphere and volatile transport? (6) What is the origin of Mercury's energetic electrons?

As during the primary mission, each of these questions is linked to a specific measurement objective designed to yield a corresponding answer. Implemented by means of the approach described below, the six measurement objectives are, respectively: (1) determine the morphological and compositional context of "hollows" and their relationship to bright crater-floor deposits and pyroclastic vents; (2) acquire targeted, high-resolution observations of volcanic materials of low impact crater density identified during the primary mission; (3) document changes in long-wavelength topography versus geological time on Mercury from altimetric and complementary imaging measurements; (4) characterize regions of enhanced exospheric density versus solar distance, proximity to specific geologic units, solar activity, and magnetospheric conditions; (5) measure changes in exospheric neutrals, plasma ions, and magnetospheric dynamics as solar activity increases; and, (6) infer the sources and energization mechanism from the location, energy spectra, and temporal profiles of energetic electrons.

Approach: The MESSENGER spacecraft accomplishes its scientific investigations with its payload of seven science instruments plus the telecommunications system for radio science (RS) [2]. The instruments include the Mercury Dual Imaging System (MDIS), which consists of an 11-color-filter wide-angle camera (WAC) and a panchromatic narrow-angle camera (NAC) mounted on a single-degree-of-freedom scan platform [3]; a Gamma-Ray and Neutron Spectrometer (GRNS), including Gamma-Ray Spectrometer (GRS) and Neutron Spectrometer (NS) sensors [4]; an X-Ray Spectrometer (XRS), including sensors that point at the planet and at the Sun [5]; a Magnetometer (MAG) [6]; the Mercury Laser Altimeter (MLA) [7]; the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), which uses a common telescope for the Ultraviolet and Visible Spectrometer (UVVS) and the Visible and Infrared Spectrograph (VIRS) [8]; and an Energetic Particle and Plasma Spectrometer (EPPS), consisting of the Energetic Particle Spectrometer (EPS) and the Fast Imaging Plasma Spectrometer (FIPS) [9].

Overarching themes as embodied in the science questions for the MESSENGER extended mission ensure that the second year of orbital operations will not be a simple continuation of the primary mission. These themes include more comprehensive measurement of the magnetosphere and exosphere during a period of more active Sun, greater focus on observations at low spacecraft altitudes, and a greater variety of targeted observations.

The MESSENGER extended mission affords a unique opportunity to observe the Mercury system under higher rates of imposed solar activity than during either the flybys or the primary mission (Fig. 1). By spanning a portion of the solar cycle not heretofore viewed at close range at Mercury, observations from the extended mission will markedly improve our ability to distinguish among proposed exospheric source

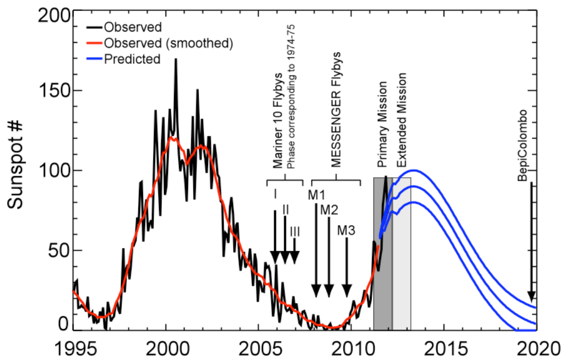

Figure 1. Sunspot number for cycle 23 and prediction for cycle 24 as of January 2012 (NASA Space Weather Prediction Center). The rise in solar activity for cycle 24 constrains the timing for the current cycle. The MESSENGER flybys occurred during a deep solar minimum. The Mariner 10 encounters (here shown at the same solar cycle phase as 1974–1975) occurred in the late declining phase. The BepiColombo spacecraft of the European Space Agency and the Japan Aerospace Exploration Agency are scheduled to arrive at the next minimum.

processes, and the range in behavior of Mercury's extraordinarily dynamic magnetosphere can be much more fully characterized. Increased solar activity corresponds to orders of magnitude greater variability in solar extreme ultraviolet (EUV) and X-ray emissions and solar energetic particle fluences, as well as a factor of 100 greater variation in solar wind forcing. The extended mission is a critical epoch for the study of Mercury's magnetosphere and exosphere, one that was not sampled by Mariner 10, will not have been observed by MESSENGER through the primary mission, and will not be viewed by BepiColombo. Moreover, because Mercury is the only solar system analog of rocky extrasolar planets orbiting near their host stars, it is of great interest to understand the broadest possible range of behavior at Mercury so that we can better interpret signatures of analogous exoplanets. A campaign of targeted observations during which EPPS or UVVS controls spacecraft pointing will permit MESSENGER to address source, loss, and transport processes for plasma and energetic particles within Mercury's magnetosphere and for neutral species in the exosphere with measurements not possible during the primary mission. Resolution of variations in the composition of Mercury's surface materials will be improved by means of the changes in both mission design and observing strategies. During the extended mission, following the reset of the periapsis to a nominal 200-km altitude, an additional orbit-correction maneuver will be employed to lower MESSENGER's apoapsis and place the spacecraft in a nominal 8-hour orbit versus the 12-hour orbit of the primary mission. The shorter orbital period, combined with the continued evolution of the periapsis latitude, results in an increase in measurement time below 500 km, for instance, increasing the sensitivity and resolution of elemental abundance measurements for spectral and morphological units on regional scales. The resulting expansion in measurements of shorter-wavelength components of Mercury's gravity field will provide improved insight into the nature of isostatic support of topography on Mercury. Extended mission measurements will also result in an improved accuracy in the higher-order structure of Mercury's internal magnetic field, diagnostic of competing models for internal field generation. An improved context for these measurements will be provided by color imaging of the northern hemisphere using fewer filters but the full spatial resolution of the MDIS instrument. Targeted observations during the extended mission will be more frequent than during the primary mission, and those targeted observations will be made with more of MESSENGER's instruments to address a greater variety of planetary processes. An emphasis during the primary mission on the production of global maps limited opportunities for targeted observations for instruments other than MDIS that require changes in spacecraft pointing. During the extended mission, MLA will make off-nadir observations of targets of high geological interest, such as candidate volcanic centers, fault structures, and impact craters. A greater range of extended-duration and directed observations by the MASCS instrument will address questions of surface mineralogical variations and exospheric dynamics beyond those that can be addressed during the primary mission.

The frequency of each type of observation and their detailed schedules will be developed by means of trade studies similar to those conducted for the primary mission, using the SciBox science planning tool [10] to evaluate the scientific merits of different observing strategies.

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