

## The MESSENGER Mission

### 1. MESSENGER Mission Overview

The MERcury Surface, Space ENVIRONMENT, GEOchemistry, and Ranging (MESSENGER) spacecraft was launched from the Cape Canaveral Air Station on 2004-08-03, on an approximately 8 year mission to become the first probe to orbit the planet Mercury.

The MESSENGER payload consists of seven instruments and a radio science (RS) experiment. The instruments are the Mercury Dual Imaging System (MDIS), the Gamma-Ray and Neutron Spectrometer (GRNS), the X-Ray Spectrometer (XRS), the Magnetometer (MAG), the Mercury Laser Altimeter (MLA), the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), and the Energetic Particle and Plasma Spectrometer (EPPS).

The MESSENGER mission is fully described in Solomon et al., 2007.

#### a. MDIS

The MDIS instrument includes both a wide-angle (WA) and a narrow-angle (NA) camera and both are capable of summing pixels. This provides for images of the surface that are of nearly uniform horizontal resolution (125 m per pixel or better throughout MESSENGER's elliptical orbit). The WA and NA cameras (WAC and NAC) are mounted on opposite sides of a pivot platform, making MDIS the only MESSENGER instrument capable of pointing independent of spacecraft attitude.

MDIS contributes to the understanding of the geological landforms and processes that shaped Mercury's surface.

#### b. GRNS

The GRNS instrument includes two sensors, a Gamma-Ray Spectrometer (GRS) and a Neutron Spectrometer (NS). The GRS is a germanium detector with an active shield capable of measuring the elemental abundances of O, Si, S, Fe, H, K, Th, and U. The NS sensor consists of two lithium glass scintillators separated by a thick slab of borated plastic scintillator. The glass scintillators measure thermal neutrons, while the borated-plastic scintillator counts fast neutrons.

GRNS contributes to the understanding of surface elemental abundances and the composition of polar deposits.

#### c. XRS

The XRS detects solar-induced X-ray fluorescence to measure the surface abundances of Mg, Al, Si, Ca, Ti and Fe. Three proportional counters measure low-energy X-rays from the planet, while a Si-PIN detector located on the spacecraft sunshade measures the solar X-ray input. The XRS has a field of view (FOV) of 12 degrees and covers an energy range from 1 to 10 keV.

XRS contributes to the understanding of surface elemental abundances.

d. MAG

The MAG instrument is a miniaturized three-axis, ring-core, fluxgate magnetometer mounted on a lightweight 3.6 m carbon-fiber boom extending from the spacecraft in the anti-sunward direction. It samples the field at a 20-Hz rate with selectable readout intervals between 0.04 s to 1 s. Readout intervals of greater than 1 s generate a 0.5 s average.

MAG contributes to the mapping of Mercury's internal magnetic field and to understanding the magnetospheric structure.

e. MLA

The MLA consists of a 1064 nm laser transmitter and four sapphire lens receiver telescopes. It is capable of measuring altitudes to a 30-cm precision at ranges up to 1000 km. Because of this range, the MLA will operate for about 30 minutes around the periapsis of each orbit.

MLA contributes to the mapping of the northern hemisphere topography and the altimetry of polar craters and is instrumental in determining Mercury's gravity field, obliquity and libration amplitude.

f. MASCS

The MASCS instrument combines a movable-grating Ultraviolet-Visible Spectrometer (UVVS) and a Visible-Infrared Spectrograph (VIRS) into one package. Both instruments share a single front-end telescope. UVVS spans the spectral range from 115 to 600 nm with an average spectral resolution of 1 nm, has a 25 km altitude resolution, and is optimized for measuring very weak exospheric emissions. VIRS measures the visible (300-1025 nm) and infrared (0.95-1.45  $\mu\text{m}$ ) spectral ranges utilizing a 512 element detector for the visible and a 256 element detector for the infrared.

MASCS contributes to the understanding of the composition of Mercury's surface in association with particular geological units, and to the understanding of neutral species in the exosphere especially near the polar regions.

g. EPPS

EPPS consists of an Energetic Particle Spectrometer (EPS) and a Fast Imaging Plasma Spectrometer (FIPS). The EPS measures the time-of-flight and residual energy of ions from 10 keV/nucleon to  $\sim 3$  MeV and electrons to 400 keV. Its FOV, 160 degrees by 12 degrees, is divided into six segments of 25 degrees each. The FIPS measures thermal and low-energy ions and is sensitive over nearly a full hemisphere, with energy per charge ( $E/q$ ) up to  $> 15$  keV/q.

EPPS contributes to the understanding of the solar environment associated with Mercury and its magnetosphere.

h. RS

The spacecraft's radio frequency (RF) telecommunications system is for communications, navigation and radio science (RS). Precise observation of the spacecraft's Doppler velocity and range are used to assist in navigating the spacecraft. These observations are inverted to determine the effect of the planet's gravitational field on the spacecraft. Occultation observations of the spacecraft's RF signal provide necessary measurements of Mercury's shape in the southern hemisphere.

RS contributes to the understanding of Mercury's gravity field, obliquity and libration amplitude (Doppler observations) and its global topography, especially the southern hemisphere (occultation observations).

## 2. Mission Phases

Nineteen mission phases were defined for significant spacecraft activity periods. The large number of phases is due to the complex sequence of gravitational assists necessary to bring the spacecraft into orbit around Mercury while maintaining a minimal mass due to fuel. This consideration led to one Earth flyby, two Venus flybys, and three Mercury flybys before orbit insertion at Mercury.

The mission phases are defined naturally by the various planetary encounters and their intervening cruise periods. Given the short encounter times for each MESSENGER flyby, we define encounter phases on the basis of a 4 week period centered on the closest approach to each target body (two weeks before and two after) and separate such encounter segments by cruise phases. The cruise periods and flybys are named according to the planetary body involved. Also defined are a launch and an orbit phase.

The mission phases are: Launch, Earth Cruise, Earth Flyby, Venus 1 Cruise, Venus 1 Flyby, Venus 2 Cruise, Venus 2 Flyby, Mercury 1 Cruise, Mercury 1 Flyby, Mercury 2 Cruise, Mercury 2 Flyby, Mercury 3 Cruise, Mercury 3 Flyby, Mercury 4 Cruise, Mercury Orbit, Mercury Orbit Year 2, Mercury Orbit Year 3, Mercury Orbit Year 4, and Mercury Orbit Year 5.

### a. Launch

The launch phase has been defined to capture instrument data produced between launch and the beginning of Phase E.

Mission Phase Start Time : 2004-08-03 (2004-216)

Mission Phase Stop Time : 2004-09-12 (2004-256)

### b. Earth Cruise

Earth Cruise is the period of time between launch and the week before closest approach to Earth.

Mission Phase Start Time : 2004-09-13 (2004-257)

Mission Phase Stop Time : 2005-07-18 (2005-199)

### c. Earth Flyby

Earth Flyby is defined as the four week (28 day) period centered on closest approach to Earth.

Mission Phase Start Time : 2005-07-19 (2005-200)

Mission Phase Stop Time : 2005-08-16 (2005-228)

d. Venus 1 Cruise

Venus 1 Cruise is defined as the period between the Earth flyby and the first Venus flyby.

Mission Phase Start Time : 2005-08-17 (2005-229)

Mission Phase Stop Time : 2006-10-09 (2006-282)

e. Venus 1 Flyby

Venus 1 Flyby is defined as the four week (28 day) period centered on the first of the mission's two closest approaches to Venus.

Mission Phase Start Time : 2006-10-10 (2006-283)

Mission Phase Stop Time : 2006-11-07 (2006-311)

f. Venus 2 Cruise

Venus 2 Cruise is defined as the period between the first and second Venus flyby.

Mission Phase Start Time : 2006-11-08 (2006-312)

Mission Phase Stop Time : 2007-05-22 (2007-142)

g. Venus 2 Flyby

Venus 2 Flyby is defined as the four week (28 day) period centered on the second of the mission's two closest approaches to Venus.

Mission Phase Start Time : 2007-05-23 (2007-143)

Mission Phase Stop Time : 2007-06-20 (2007-171)

h. Mercury 1 Cruise

Mercury 1 Cruise is defined as the period between the second Venus flyby and first Mercury flyby.

Mission Phase Start Time : 2007-06-21 (2007-172)

Mission Phase Stop Time : 2007-12-30 (2007-364)

i. Mercury 1 Flyby

Mercury 1 Flyby is defined as the four week (28 day) period centered on the first of the mission's three closest approaches to Mercury.

Mission Phase Start Time : 2007-12-31 (2007-365)

Mission Phase Stop Time : 2008-01-28 (2008-028)

j. Mercury 2 Cruise

Mercury 2 Cruise is defined as the period between the first and second Mercury flyby.

Mission Phase Start Time : 2008-01-29 (2008-029)

Mission Phase Stop Time : 2008-09-21 (2008-265)

k. Mercury 2 Flyby

Mercury 2 Flyby is defined as the four week (28 day) period centered on the second of the mission's three closest approaches to Mercury.

Mission Phase Start Time : 2008-09-22 (2008-266)

Mission Phase Stop Time : 2008-10-20 (2008-294)

l. Mercury 3 Cruise

Mercury 3 Cruise is defined as the period between the second and third Mercury flyby.

Mission Phase Start Time : 2008-10-21 (2008-295)

Mission Phase Stop Time : 2009-09-15 (2009-258)

m. Mercury 3 Flyby

Mercury 3 Flyby is defined as the four week (28 day) period centered on the third of the mission's three closest approaches to Mercury.

Mission Phase Start Time : 2009-09-16 (2009-259)

Mission Phase Stop Time : 2009-10-14 (2009-287)

n. Mercury 4 Cruise

Mercury 4 Cruise is defined as the period between the third Mercury flyby and Mercury orbit insertion.

Mission Phase Start Time : 2009-10-15 (2009-288)

Mission Phase Stop Time : 2011-03-03 (2011-062)

o. Mercury Orbit

The Orbit phase begins at Mercury orbit insertion and continues until the end of mission. This phase begins the most intensive science portion of the mission with full instrument utilization throughout the period.

Mission Phase Start Time : 2011-03-04 (2011-063)

Mission Phase Stop Time : 2012-03-17 (2012-077)

p. Mercury Orbit Year 2

The Orbit phase year 2 begins the extended mission. This phase continues the most intensive science portion of the mission with full instrument utilization throughout the period.

Mission Phase Start Time : 2012-03-18 (2012-078)

Mission Phase Stop Time : 2013-03-17 (2013-076)

q. Mercury Orbit Year 3

The Orbit phase year 3 continues the extended mission. This phase continues the most intensive science portion of the mission with full instrument utilization throughout the period.

Mission Phase Start Time : 2013-03-18 (2013-077)

Mission Phase Stop Time : 2014-03-17 (2014-076)

r. Mercury Orbit Year 4

The Orbit phase year 4 continues the extended mission. This phase continues the most intensive science portion of the mission with full instrument utilization throughout the period.

Mission Phase Start Time : 2014-03-18 (2014-077)

Mission Phase Stop Time : 2015-03-17 (2015-076)

s. Mercury Orbit Year 5

The Orbit phase year 5 continues the extended mission through to the end of orbital operations. This phase continues the most intensive science portion of the mission with full instrument utilization through near the end of the period which ended when the spacecraft impacted Mercury as expected on 30 April 2015.

Mission Phase Start Time : 2015-03-18 (2014-077)

Mission Phase Stop Time : 2015-04-30 (2015-120)

### 3. Mission Objectives

a. Primary Mission

The primary MESSENGER mission has six guiding science questions, which in turn correlate to specific science objects and a set of measurement requirements related to specific instruments. These guiding questions are:

- What planetary formational processes led to the high metal/silicate ratio in Mercury?
- What is the geological history of Mercury?
- What are the nature and origin of Mercury's magnetic field?
- What are the structure and state of Mercury's core?

- What are the radar-reflective materials at Mercury's poles?
- What are the important volatile species and their sources and sinks on and near Mercury?

The related science objectives and instrument measurement requirements are:

- Map the elemental and mineralogical composition of Mercury's surface.
  - GRNS and XRS: Provide major-element maps of Mercury to 10% relative uncertainty on the 1000-km scale. Elements to be measured include: O, Si, S, Fe, H, K, U (by GRS); thermal and epithermal neutrons (by NS), and Fe, Mg, Ca, Al, Si, Ti, S (by XRS).
  - MASCS (VIRS): Determine local composition and mineralogy at the ~20-km scale.
- Image globally the surface at a resolution of hundreds of meters or better.
  - MDIS (WAC): Provide a global multi-spectral map at 2 km/pixel average resolution.
  - MDIS (NAC): Provide a global map with > 90% coverage (monochrome) at 250-m average resolution.
  - MDIS: Image > 80% of the planet stereoscopically. Provide color images with a resolution to 1 km/pixel.
  - MLA: Sample half of the northern hemisphere for topography at 1.5-m average height resolution
- Determine the structure of the planet's magnetic field.
  - MAG: Provide a multipole magnetic-field model resolved through quadrupole terms with an uncertainty of less than ~20% in the dipole magnitude and direction.
- Measure the libration amplitude and gravitational field structure.
  - MLA & RS: Provide a global gravity field to degree and order 16 and determine the ratio of the solid-planet moment of inertia to the total moment of inertia to ~20% or better.
- Determine the composition of the radar-reflective materials at Mercury's poles.
  - GRNS: Identify the principal component of the radar-reflective material at Mercury's north pole.
- Characterize exosphere neutrals and accelerated magnetosphere ions.
  - MASCS (UVVS): Provide altitude profiles at 25-km resolution of the major neutral exospheric species.
  - EPPS: Characterize the major ion-species energy distributions as functions of local time, Mercury Heliocentric distance, and solar activity.

#### b. First Extended Mission

The first extended MESSENGER mission has six additional guiding science questions, which in turn correlate to specific science objects and a set of measurement requirements related to specific instruments. These guiding questions are:

- What are the sources of surface volatiles?
- How late into Mercury's history did volcanism persist?
- How did Mercury's long-wavelength topography change with time?
- What is the origin of localized regions of enhanced exospheric density near Mercury?

- How does the solar cycle affect Mercury's exosphere and volatile transport?
- What is the origin of Mercury's energetic electrons?

The related science objectives and instrument measurement requirements are:

- Determine the morphological and compositional context of 'hollows' and their relationship to bright crater-floor deposits and pyroclastic vents.
  - MDIS (WAC): Image 70% of the planet in three colors at 600 m/pixel average spatial resolution. MDIS (NAC): Acquire 100 sets of targeted images of hollows or pyroclastic vents at 60 m/pixel average spatial resolution. MASCS (VIRS): Acquire 20 targeted VIRS observations of hollows and pyroclastic vents at low solar incidence angle ( $i$ ).
- Acquire targeted, high-resolution observations of volcanic materials of low impact crater density identified in the primary mission.
  - MDIS (NAC): Acquire 30 sets of targeted images of young volcanic materials at 60 m/pixel average spatial resolution.
- Document changes in long-wavelength topography versus geological time on Mercury from altimetric and complementary imaging measurements MDIS: Image 70% of the planet at 250 m/pixel average spatial resolution, targeting  $i \sim 40$  deg. to 65 deg.
  - MDIS: Image 70% of the planet at 250 m/pixel average spatial resolution, targeting  $i \sim 75$  deg. to 85 deg., and MLA: Provide topographic profiles over 10 broadly elevated regions and the floors of 50 complex impact craters, including volcanically flooded craters.
- Characterize regions of enhanced density versus solar distance, proximity to geologic units, solar activity, and magnetospheric conditions.
  - MASCS (UVVS): Survey dayside and nightside exosphere emissions at an average rate of once every third orbit, MASCS (UVVS): During dawn-dusk seasons, conduct repeated observations of exospheric emission over both poles to the maximum extent permitted by spacecraft pointing constraints, and MASCS (UVVS): Conduct full-orbit, exosphere observation campaigns at equally spaced Mercury true anomalies over each of four Mercury years.
- Measure changes in exospheric neutrals and plasma ions as solar activity increases.
  - EPPS (FIPS): Measure the global distribution of planetary ions and the direction of plasma flow, within operational constraints.
- Infer the sources and energization mechanism from the location, energy spectra, and temporal profiles of energetic electrons.
  - EPPS (EPS) & MAG: Provide locations, energy spectra and pitch angles, and temporal profiles of energetic electrons across all magnetic longitudes in the northern hemisphere.

### c. Second Extended Mission

The second extended MESSENGER mission has seven additional guiding science questions, which in turn correlate to specific science objects and a set of measurement requirements related to specific instruments. These guiding questions are:

- What active and recent processes have affected Mercury's surface?
- How has the state of stress in Mercury's crust evolved over time?
- How have the compositions of volcanic materials on Mercury evolved over time?
- What are the characteristics of volatile emplacement and sequestration in Mercury's north polar region?
- What are the consequences of precipitating ions and electrons at Mercury?
- How do Mercury's exosphere and magnetosphere respond to both extreme and stable solar wind conditions during solar maximum and the declining phase of the solar cycle?
- What novel insights into Mercury's thermal and crustal evolution can be obtained with high-resolution measurements from low altitudes?

The related science objectives and instrument measurement requirements are:

- Characterize faulted terrain by acquiring at least one of the following: (a) 20 NAC along-track stereo pairs or (b) 40 MLA topographic profiles.
- Characterize fresh craters by acquiring at least one of the following: (a) 20 WAC 11-color image sets or (b) 20 NAC along-track stereo pairs.
- Characterize hollows by acquiring (a) UVVS observations of exospheric species over eight clusters of hollows on three different dates and from two different viewing geometries per feature or (b) 20 along-track NAC stereo pairs and 20 11-color image sets each.
- Characterize surface features at very high resolution by acquiring 750 NAC images at  $\leq 10$ -m pixel scale and 100 NAC images at  $\leq 5$ -m pixel scale.
- Search for color variations within the northern plains by acquiring 5-color MDIS images of 75% of the surface area north of 60 deg N at phase angles  $< 60$  deg.
- Constrain the elemental composition of spectral end-member materials by acquiring targeted XRS spectra from (a) the large pyroclastic deposit northeast of Rachmaninoff and (b) of at least two different portions of low-reflectance blue plains exterior to the Caloris basin. For each target, acquire a minimum of 1000 s of spectral integration spread over at least five different orbits.
- (a) Characterize MLA-bright and dark materials by acquiring MLA ranging and reflectance data along portions of two orbits for which ground tracks cross each of 10 craters  $< 20$  km in diameter, and (b) characterize the north polar hydrogen distribution at high spatial resolution by acquiring NS measurements for 70% of the time that the spacecraft altitude is less than 150 km.
- Characterize crustal structure at high resolution by acquiring Doppler tracking data for portions of 100 orbits at altitudes  $< 100$  km.
- Characterize the structure of crustal magnetization at high resolution by acquiring MAG and FIPS observations along portions of 100 orbits at altitudes  $< 50$  km in the vicinity of the northern plains.
- Characterize magnetospheric particle flows and pitch-angle distributions by acquiring a defined set of 970 EPPS measurements distributed across several different pointing scenarios.

- Characterize the exospheric response to conditions during solar maximum and the declining phase of the solar cycle by acquiring a defined set of 5025 UVVS dayside and nightside observations, including searches for species with weaker resonant emissions.
- Characterize the magnetospheric response to conditions during solar maximum and the declining phase of the solar cycle by acquiring MAG, EPPS and NS/GRS observations for 75% of the time throughout the mission, including times at which the spacecraft altitude is < 50 km.

#### 4. References Cited

Solomon, S.C., R.L. McNutt, Jr., R.E. Gold, and D.L. Domingue, MESSENGER mission overview, *Space Science Reviews*, 131, 3-39, 2007.