MESSENGER: THE REDISCOVERY OF MERCURY. Sean C. Solomon[1], Ralph L. McNutt, Jr.[2], Robert E. Gold[2], Andrew G. Santo[2], and the MESSENGER Team, [1]Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, DC 20015 (scs@dtm.ciw.edu), [2]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723.

Introduction. Mercury is an extraordinary planet. The closest planet to the Sun, Mercury has the largest diurnal range in surface temperature yet has polar deposits that may consist of water ice [1]. Mercury is the only planet locked in a spin-orbit resonance, an important though poorly understood constraint on dynamical and internal evolution [2]. It has the largest uncompressed density and, by inference, the greatest mass fraction of iron-nickel of any planet or satellite [3], a compositional anomaly that is a critical clue, not yet deciphered, to the processes by which the inner planets formed [4-7]. Mercury has a strong internal magnetic field and presumably a hydromagnetic dynamo in a fluid outer core [8], yet the known portion of the surface has a density of impact craters indicating that geological activity largely ceased early in planetary history [9]. Mercury's magnetic field gives rise to a small magnetosphere with many similarities to that of the Earth [10], yet the presence of only a tenuous atmosphere and ionosphere [11] and the greater proximity to the Sun affect the nature of solar wind interaction with the planet in ways still poorly discerned.

Mercury is also the least explored planet save Pluto. Most of what is known comes from the three flybys of Mercury by Mariner 10 in 1974 and 1975. With the recognition that gravity-assisted trajectories, using the launch systems available in the Discovery Program, now permit the insertion of a spacecraft into Mercury orbit [12], the need for the intensive exploration of the innermost planet has recently been recognized in NASA plans. A Mercury orbiter is central to two of the campaigns described in the Solar System Exploration Roadmap (Formation and Dynamics of Earth-Like Planets, and Astrophysical Analogs in the Solar System), and such a mission has been identified as important in NASA's Space Science Enterprise Strategic Plan.

Under NASA's Discovery Program, the Carnegie Institution of Washington and The Johns Hopkins University Applied Physics Laboratory have proposed MESSENGER, a *ME*rcury *S*urface, *S*pace *EN*vironment, *GE*ochemistry and *R*anging mission to orbit Mercury for one Earth year after completing two flybys of that planet and two flybys of Venus. The flybys will return significant new data early in the mission, while the orbital phase, guided by the flyby data, will perform a focused scientific investigation of this least-studied terrestrial planet. Answers to key questions about Mercury's high density, crustal composition and structure, volcanic history, core structure, magnetic field generation, polar deposits, exosphere, overall volatile inventory, and magnetosphere will be provided by an optimized set of miniaturized space instruments.

Additional members of the MESSENGER consortium include Composite Optics, Inc., a leader in light-weight spacecraft structures, GenCorp Aerojet, a leader in spacecraft propulsion systems, Goddard Space Flight Center, the University of Colorado, and the University of Michigan. Co-engineered with planetary scientists from twelve institutions, MESSENGER has been designed to accommodate the severe near-Sun thermal environment and supply the required large spacecraft velocity change while enabling all science observations. The integrated structure, propulsion system, and thermal design; fully-redundant integrated electronics module for avionics functions; dual phased-array antennas; radiation-hardened, high-temperature solar panels; and high level of spacecraft autonomy provide robust margins.

To engage students and the public, the MESSENGER Education and Outreach Plan, coordinated by the American Association for the Advancement of Science, targets segments of the population at all levels of education and privilege. The plan is designed to meet or exceed the National Science Education Standards as well as NASA education goals. Through the public awareness component of the program, all Americans and the greater world community will have the opportunity to share in the technical challenges faced by the MESSENGER mission and the renewed exploration of Mercury and the inner solar system.

Scientific Objectives. A substantially improved knowledge of Mercury will add critical new insight into how terrestrial planets formed and evolved. Determining the composition of Mercury, with its anomalously high ratio of metal to silicate, will provide a unique window on the processes by which planetesimals in the primitive solar nebula accreted to form planets. Documenting the global geological history will elucidate the role of planet size as a governor of magmatic and tectonic history for a terrestrial planet. Characterizing the nature of the magnetic field of Mercury and the size and state of Mercury's core will allow us to generalize our understanding of the energetics and lifetimes of magnetic dynamos in solid planets and satellites. Determining the nature of volatile species in Mercury's polar deposits, exosphere, and magnetosphere will provide critical insight into volatile inventories, sources, and sinks in the inner solar system.

Key questions to be addressed by MESSENGER include:

What planetary formational processes led to the high metal/silicate ratio in Mercury?

What is the geological history of Mercury?

What is the nature and origin of Mercury's magnetic field?

What is 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 rationale linking these questions to the mission measurement requirements and instrument suite begins with the scientific objectives, which are, in order of priority, to determine (1) the chemical composition of Mercury's surface, (2) the planet's geological history, (3) the nature of Mercury's magnetic field, (4) the size and state of the core, (5) the volatile inventory at Mercury's poles, and (6) the nature of Mercury's exosphere and magnetosphere. Objective (1) leads to a measurement requirement for global maps of elemental composition at a resolution sufficient to discern major units and to distinguish material excavated and ejected by young impact craters from a possible veneer of cometary and meteoritic material; information on surface mineralogy is also important. Objective (2) leads to the requirement for global monochrome imaging at a resolution of hundreds of meters or better, topographic profiles across key geological features from altimetry or stereo, and spectral measurements of major geologic units at spatial resolutions of several kilometers or better. Objective (3) leads to a requirement for magnetometry, both near the planet and throughout the magnetosphere, as well as for energetic particle and plasma measurements so as to isolate external from internal fields. Objective (4) can be met by altimetric measurement of the amplitude of Mercury's physical libration and determination of the planet's obliquity and low-degree gravitational field. Objective (5) can be met by remote and in situ identification of neutral and charged species in the polar atmosphere, remote assessment of surface composition, particularly hydrogen content, and imaging and altimetry of polar-region craters. Objective (6) leads to measurement requirements for the identification of all major neutral species in the exosphere and all charged species in the magnetosphere.

Measurement Requirements. The MESSENGER measurement requirements are met by a suite of seven scientific instruments plus the spacecraft communication system. There is a dual imaging system for wide and narrow fields-of-view, monochrome and color imaging, and stereo; X-ray and combined gamma-ray and neutron spectrometers for surface chemical mapping; a magnetometer; a laser altimeter; a combined UV-visible and visible-near-infrared spectrometer to survey both exospheric species and surface mineralogy; and an energetic particle and plasma spectrometer to sample charged species in the magnetosphere. The payload instrumentation provides functional redundancy across scientific objectives and yields important consistency checks of results obtained with more than one instrument.

Mission Design. The baseline MESSENGER mission employs state-of-the-art chemical propulsion and multiple gravitational flybys to reach Mercury orbit. Both the flybys and the orbit have been optimized to satisfy all scientific measurement requirements while meeting the constraints of the Discovery Program. The mission profile has also been carefully tailored to include prudent schedule and mass margins and reserves. Fuel reserves and maneuver schedule margins are included to provide resiliency and to minimize risk in mission implementation. There are no other mission designs for the coming decade that can reach Mercury with this level of redundancy using tried-and-tested technology.

After launch by a Delta II 7925H, an Earth flyby, two flybys of Venus, and two flybys of Mercury are needed before orbit insertion at the third Mercury encounter. Orbital science observations are then carried out for one Earth year. The periapsis altitude and orbit phasing for MESSENGER are optimized to balance thermal constraints against science requirements. The inclination and latitude of periapsis result from a complex set of trade-space optimizations driven by imaging and altimetry coverage requirements as well as thermal input and spacecraft mass.

Expected Data. During the flybys of Mercury, regions unexplored by Mariner 10 will be seen for the first time. New data will be gathered on Mercury's exosphere and magnetosphere as will the first information on surface composition. Approach and departure movies as well as high-resolution imagery will bring the mission alive to both the scientific community and the public at large. During the orbital phase of the mission, MESSENGER's science strategy shifts to detailed global mapping; characterization of the exosphere, magnetosphere, and polar deposits; acquisition of gravity field and topographic data for geophysical studies; and focused investigation of high-priority targets identified during the flybys. All mission data will be provided to the Planetary Data System and the scientific community as soon as processing and validation are complete. Public dissemination of images and data, in electronic and printed formats, will start immediately following receipt. Optimal use will be made of the World Wide Web to provide results to the scientific community, to mission educational and outreach endeavors, and to the general public.

References. [1] J. K. Harmon, *Adv. Space Res.*, *19*, 1487, 1997; [2] S. J. Peale, in *Mercury*, Univ. Arizona, p. 461, 1988; [3] R. W. Siegfried II and S. C. Solomon, *Icarus*, *23*, 192, 1974; [4] S. J. Weidenschilling, *Icarus*, *35*, 99, 1978; [5] A. G. W. Cameron, *Icarus*, *64*, 285, 1985; [6] J. S. Lewis, in *Mercury*, Univ. Arizona, p. 651, 1988; [7] G. W. Wetherill, in *Mercury*, Univ. Arizona, p. 670, 1988; [8] J. E. P. Connerney and N. F. Ness, in *Mercury*, Univ. Arizona, p. 494, 1988; [9] R. G. Strom, *Adv. Space Res.*, *19*, 1471, 1997; [10] C. T. Russell, D. N. Baker, and J. A. Slavin, in *Mercury*, Univ. Arizona, p. 514, 1988; [11] D. M. Hunten, T. H. Morgan, and D. E. Shemansky, in *Mercury*, Univ. Arizona, p. 562, 1988; [12] C.-W. Yen, *J. Astron. Sci.*, *37*, 417, 1989.