THE MESSENGER SCIENTIFIC PAYLOAD.

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Introduction: The MErcury, Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft will be the first to orbit the planet Mercury and the first spacecraft to visit Mercury in more than 30 years. MESSENGER will launch in March 2004 with a miniaturized set of seven instruments. Along with the spacecraft telecommunications system, these instruments will provide a comprehensive view of the structure and composition of the planet. MESSENGER will orbit Mercury for one Earth year following two flybys of Venus and two of Mercury.

Mercury, the least studied of the terrestrial planets, holds the prospect for unraveling important aspects of the origin and early history of the solar system [1]. Mercury is a challenging body to orbit, however, because of high propulsive-energy requirements and the severe thermal environment [2]. To date, Mercury has been visited by spacecraft only during three flybys by Mariner 10 in 1974 and 1975.

The MESSENGER mission has been designed on the basis of a detailed progression from the science questions to be answered, through mission design and implementation [1], to the instrument suite needed to obtain the necessary data. By adhering strictly to the science requirements while also pursuing aggressively miniaturization and packaging optimization so as to minimize payload mass, the instrument suite meets all mission constraints while enabling the measurements required for addressing fully the science questions that define the mission.

Instrument Suite: MESSENGER carries seven scientific instruments plus radio science. The instrument suite includes the Mercury Dual Imaging System (MDIS), a Gamma-Ray and Neutron Spectrometer (GRNS), an X-ray Spectrometer (XRS), a Magnetometer (MAG), the Mercury Laser Altimeter (MLA), the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), an Energetic Particle and Plasma Spectrometer (EPPS), and Radio Science (RS). MDIS has both a wide-angle (WA) and a narrow-angle (NA) imager. MASCS includes an Ultraviolet-Visible Spectrometer (UVVS) and a Visible-Infrared Spectrograph (VIRS). EPPS includes an Energetic Particle Spectrometer (EPS) sensor and a Fast Imaging Plasma Spectrometer (FIPS). The MESSENGER instruments capitalize on emerging technologies developed over several years. The selected instruments accomplish the required observations at low cost with the low masses essential for implementing this difficult mission. Mass restrictions on a Mercury mission are severe. The total mass available for the payload, including all electronics, thermal accommodations, booms, brackets, and cables, is about 47 kg.

All instruments except MAG are fixed and body mounted for high reliability and low cost. The directional instruments are all co-aligned and located on the bottom deck of the spacecraft. Despite the extreme thermal inputs from the Sun and Mercury, the MESENGER spacecraft design provides a benign thermal environment for the payload.

A compact, shared data-processing unit (DPU) supports all of the instruments. In addition, most instruments have a miniature data processing unit to perform their real-time, event-by-event processing. Because of the limited downlink bandwidth available, several lossless and lossy data compression techniques are provided to the instruments as required.

Mercury Dual Imaging System: MDIS combines a 12-filter WA imager (10.5° field of view), with a high-resolution, NA imager (1.5° FOV) on a small pivot platform. Both imagers have 1024x1024 pixels and 12-bit quantization. The pivot platform provides for full coverage of the planet during orbital operations and during the two Mercury flybys. Each imager has manual and automatic exposure control over a range of 1 ms to 10 s with electronic shuttering. A subframing capability allows the selection of a chosen rectangular segment of the image to be saved and downlinked. Several image-compression techniques are available and may be used individually or in combination.

Gamma-Ray and Neutron Spectrometer:. GRNS has an active-shielded γ-ray scintillator that measures a range of elemental abundances (O, Si, Fe, H, K) and a neutron spectrometer to provide high sensitivity to possible H_2O ice at Mercury's poles. The γ-ray spectrometer (GRS) scintillator is mounted in a cup-shaped active shield of bismuth germanate (BGO) 1.25 cm thick. The shield defines a ~ 45° FOV, provides an anticoincidence veto for cosmic rays, protects the central scintillator from locally generated backgrounds, reduces the Compton continuum, and captures escaping γ-rays generated by pair-production in the central scintillator. The primary GRS detector is a 50 x 50 mm cesium iodide (CsI) scintillator. Energy resolution better than 8.0% has been demonstrated. CsI works near room temperature, so cryogenic cooling is not required, and it is nearly immune to radiation damage, important for this long-duration mission. The neutron spectrometer uses two lithium glass scintillators separated by a block of borated-polymer scintillator to measure thermal, epithermal and fast neutrons..

X-ray Spectrometer: XRS is an improved version of the NEAR Shoemaker X-ray spectrometer design [3]. Three gas proportional counters view the planet, and a state-of-the-art Si-PIN detector views the sun. Thin absorption filters on two of the planet-facing detectors differentially separate the lower energy X-ray lines (Al, Mg, and Si) [4]. A Be-Cu honeycomb collimator provides a 12° FOV. Energy spectra are accumulated from 1 to 10 keV, which covers the K-fluorescence emission lines of the elements Mg, Al, Si, S, Ca, Ti, and Fe.

Magnetometer: MAG is a miniature three-axis, ring-core fluxgate magnetometer mounted on a 3.6-m boom in the anti-sunward direction. The principal range is ± 2048 nT with 16-bit quantization. There are selectable averaging intervals from 0.04 s to 1 s. An extensive program is in place to minimize stray spacecraft magnetic fields. Potential magnetic field sources are identified early in the design process, and mitigation techniques are selected for their minimum impact on the design.

Mercury Laser Altimeter: MLA will determine the topography of Mercury in the northern hemisphere where the MESSENGER orbit is less than 1000 km above the surface. A Q-switched, diode-pumped Cr:Nd:YAG laser transmitter operates at 1064 nm. When the laser fires, a small fraction of the laser beam is sampled by an optical fiber and relayed onto the start detector, which initiates the timing process. A 4-lens refractive receiver telescope, collects the back-scattered laser echo pulses which are detected with a hybrid avalanche photodiode assembly. Receiver electronics record the arrival time of individually reflected photons with 75-cm (5-ns) resolution.

Mercury Atmospheric and Surface Composition Spectrometer: MASCS is derived from the Galileo Ultraviolet Spectrometer (UVS) [5]. UVVS is optimized for measuring the composition and structure of the atmosphere and surface reflectance. VIRS is optimized for measuring visible (VIS) and near-infrared (IR) surface reflectance (0.3-1.45 µm). VIRS is mounted on top of the UVVS and is coupled to the telescope focal plane with a short optical fiber. UVVS has 25 km resolution at the limb; VIRS has 100-m to 7.5-km resolution on the surface of Mercury, depending on altitude.

A Cassegrain telescope feeds an 1800-groove/mm Ebert-Fastie diffraction grating spectrometer in the UVVS. The spectrum is scanned by rotating the grating in 0.25 nm steps, providing a factor of 4 oversampling. Three small photomultiplier tubes, behind separate slits, are used in pulse-counting mode for the atmospheric observations.

The VIRS concave holographic diffraction grating images onto two semiconductor detectors. The visible detector (300-1025 nm) is a 512-element silicon line array. The IR detector (0.95-1.45 µm) is a 256-element InGaAs array. Both detectors are digitized to 12 bits.

Energetic Particle and Plasma Spectrometer: EPPS measures ions from thermal plasmas through ~5 MeV and electrons from ~20 keV to 400 keV. EPPS combines a Fast Imaging Plasma Spectrometer (FIPS) head and an Energetic Particle Spectrometer (EPS) head for energetic ions and electrons. EPPS is mounted near the top deck of the spacecraft where it can observe low-energy ions coming up from the surface of Mercury, pickup ions, ions and electrons accelerated in the magnetosphere, and the solar wind when the spacecraft is turned near its maximum allowed off-Sun pointing angle. EPS is a hockey-puck-sized, time-of-flight (TOF) spectrometer that measures the energy spectra, atomic composition, and pitch-angle distributions of energetic ions and electrons. The FOV is 160° by 12° with six active segments of 25° each; the geometric factor is ~0.1 cm^2sr.

FIPS measures low-energy plasmas with a nearly full hemispherical coverage. Particles pass through an innovative electrostatic deflection system into a position-sensing TOF telescope. The mass per charge of a given ion follows from E/q and the TOF, allowing reconstruction of distribution functions for different mass/charge species.

Radio Science: RS observations are required for measurements of Mercury's gravity field and in support of the laser altimetry investigation. Accurate knowledge of spacecraft location is required to recover the magnitude of the physical libration of the planet, a key mission objective [1]. Tracking will determine the spacecraft velocity to 0.1 mm/s root-mean-square error.

References: [1] Solomon, S. C., et al., The MESSENGER mission to Mercury: Scientific objectives and implementation. (2001, in press) *Planet. Space Sci.* [2] Santo, A. G., et al., The MESSENGER mission to Mercury: Spacecraft and mission design (2001, in press) *Planet. Space Sci.* [3] Trombka, J. I., et al. (1997) *JGR*, *102*, 23,729-23,750. [4] Trombka, J. I., et al. (2000) *Science, 289*, 2101-2105. [5] Hord, C. W., et al. (1992) *Space Sci. Rev. 60*, 503-530.