MESSENGER SCIENCE OBSERVATION PLANNING FOR ORBITAL OPERATIONS AT MERCURY.

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Introduction: The MESSENGER spacecraft [1] will be inserted into orbit about Mercury on 18 March 2011, marking the beginning of the one-year orbital mission phase [2]. After a two-week orbit commissioning period, a choreographed program of science observations will begin. Because the orbital mission phase spans two Mercury solar days, the surface mapping observations must be planned for the entire year in advance to ensure coverage of the entire planet under acceptable illumination and viewing geometries. In addition, topography, surface composition, radio science, exosphere, and magnetosphere observation campaigns must be coordinated to ensure that each investigation acquires the data required for its respective objectives. To accomplish this goal the SciBox science observation simulation tool has been adapted and substantially enhanced to plan the entire year-long campaign of payload and spacecraft science pointing commanding. SciBox provides full geometry simulation, spacecraft constraints and subsystem performance modeling, science investigation opportunity analyzers, and command request generators. The tool enables re-simulation and generation of mission-long commanding in run times of a few hours so that adjustments to the science observation plan will be made efficiently throughout the orbital mission.

Science Observation Objectives: The MESSENGER mission addresses six scientific questions [2]: (1) What planetary formational processes led to the high ratio of metal to silicate in Mercury? (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 on and near Mercury?

These questions govern the observation objectives for the seven instruments and the radio science (RS) investigation. The on-board instruments include a Mercury Dual-Imaging System (MDIS) for multispectral imaging of Mercury's surface; a Gamma-Ray and Neutron Spectrometer (GRNS) and an X-Ray Spectrometer (XRS) for remote geochemical mapping; a Magnetometer (MAG) to measure the planetary magnetic field; the Mercury Laser Altimeter (MLA) to measure topography and planetary shape; the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), consisting of the Visible Infrared Spectrograph (VIRS) and the Ultraviolet and Visible Spectrometer (UVVS); and an Energetic Particle and Plasma Spectrometer (EPPS), which includes a Fast Imaging Plasma Spectrometer (FIPS) and an Energetic Particle Spectrometer (EPS) [3]. The observation objectives are organized by activity type, as summarized in Table 1. The MASCS, XRS, GRNS, and MLA instruments are mounted with a common boresight normal to the direction to the center of the spacecraft sunshade. The MDIS cameras are mounted on a pivot that provides some freedom to view sunward and anti-sunward of the common instrument boresight direction.

Table 1. MESSENGER Science Observation Activities.

Observation activity	**Measurement requirements and relevant instrument/investigation**
Global surface mapping	Monochrome imaging with > 90% coverage at 250-m average resolution or better for geology characterization: MDIS Multispectral imaging with > 90% coverage at 2 km/pixel average resolution or better for mineralogy: MDIS Stereoscopic imaging with > 80% coverage for global topography: MDIS Elemental abundance determination: GRNS, XRS High-resolution spectral measurements of geological units for mineralogy: VIRS
Northern hemisphere and polar region observations	Northern hemisphere topography measurement for obliquity and libration amplitude determination: MLA Composition of polar deposits: GRNS Polar ionized species measurement for volatile identification: EPPS Polar exosphere measurement for volatile identification: UVVS
In-situ observations	Mapping magnetic field to characterize the internally generated field: MAG Determining magnetosphere structure, plasma pressure distributions, and their dynamics: MAG, EPPS Solar wind pick-up ions to understand volatiles: EPPS
Exosphere survey	Neutral species in exosphere to understand volatiles: UVVS
Region-of-interest targeting	High-resolution imaging, spectroscopy, photometry to support geology, mineralogy, and topography: MDIS
Radio science measurements	Gravity field determination to support characterization of internal structure (in combination with topography and libration): RS

Constraints: The three primary operational constraints that the MESSENGER spacecraft must obey while in orbit are related to thermal control, power, and solid-state recorder (SSR) space [1]. At Mercury the solar flux is up to 11 times higher than it is at Earth. A 2.5 m × 2 m sunshade on one side of the spacecraft body shields the instruments and spacecraft systems other than the solar panels. The guidance and control system includes strict rules to keep the spacecraft attitude within a $6^o \times 5^o$ angular Sun-keep-in (SKI) boundary relative to the center of the sunshade.

During some orbits around Mercury, MESSENGER will pass in the shadow of the planet. When these eclipses last longer than 35 minutes, there will not be sufficient power from the batteries to power all of the instruments, and both instrument operations and spacecraft pointing are constrained to keep the spacecraft operating safely.

The SSR is an 8-Gbit synchronous dynamic random access memory (SDRAM), and the science data accumulation must always fit within this limit to avoid loss of data. All instruments employ data compression, and MDIS also uses image binning to keep the volume of extraneous data to a minimum. In addition, data volume generation and downlink are simulated to ensure that the memory space is never exceeded.

Observation Simulation and Planning: Due to the complex observing geometry and spacecraft operational constraints, science observation planning requires a complete orbital mission simulation tool that accurately represents the constraints, spacecraft pointing capabilities, mission operations activities, instrument data generation, and data downlink. The observational activities listed in Table 1 are scientifically ambitious, operationally challenging, and in some cases require mutually exclusive spacecraft pointing.

1st Solar Day	2nd Solar Day
Eclipse	Eclipse
Orbit Correction Maneuver	Orbit Correction Maneuver
Mercury Orbit Insertion	G&C High Rate
G&C High Rate	Downlink - High Gain Antenna
Downlink - High Gain Antenna	Priority-1 Targets & VIRS phot 1
Post MOI	UVVS Polar Exosphere Scan
Priority-1 Targets & VIRS phot 1	MDIS Stereo Mapping
UVVS Polar Exopshere Scan	MLA North Polar Off-Nadir Coverage
MLA Northern Hemisphere Nadir Coverage	MLA Northern Hemisphere Nadir Coverage
Priority-2 Targets & VIRS phot 2	Priority-2 Targets & VIRS phot 2
MDIS-WAC South Pole Monitoring	MDIS NAC 3x2 South
UVVS Star Calibration	UVVS Star Calibration
XRS Star Calibration	XRS Star Calibration
MDS Limb Scan/Pivot Cal	MDS Limb Scan/Pivot Cal
UVVS Limb Scan	UVVS Limb Scan
Priority-3 Targets & VIRS phot 3	Priority-3 Targets & VIRS phot 3
XRS/VIRS Global Mapping	XRS/VIRS Mapping
MDIS Global Color Mapping	Priority-4 Targets & VIRS phot 4
MDIS Global Monochrome Mapping	UVVS Exosphere Scan
Priority-4 Targets & VIRS phot 4	MDIS North Polar Ride-Along
UVVS Exosphere Scan	MAG Observation
MAG Observation	GRS Northern Hemisphere Coverage
GRS Northern Hemisphere Coverage	NS Northern Hemisphere Coverage
NS Northern Hemisphere Coverage	EPS Observation
EPS Observation	FIPS Observation
FIPS Observation	RS - Low Gain Antenna
RS -Low Gain Antenna	Priority-5 Ride-Along Targeted Observations
Priority-5 Ride-Along Targeted Observations	Priority-6 Ride-Along Targeted Observations
Priority-6 Ride-Along Targeted Observations	Priority-7 Ride-Along Targeted Observations
Priority-7 Ride-Along Targeted Observations	

Key:	G&C Commanding Required
	No G&C commanding
	Pivot commanding only

Figure 1. Activity pointing prioritization order (highest at top) for each of the two solar days of MESSENGER observations at Mercury.

To accomplish this suite of activities the concepts of operations for each investigation were captured as algorithms in the SciBox mission simulation tool and used to derive opportunities for each investigation. These opportunities were then integrated using the activity pointing prioritization shown in Figure 1 to generate an integrated schedule. There are two different scheduling priority orders, one for each of the two solar days. The scheduling priority for the first solar day is biased toward mapping observations, and the scheduling priority for the second solar day is tailored toward gap coverage, high-resolution targeting, and other specific campaigns. This ordering of activities between solar days provides margin for the more critical observations conducted on the first solar day. The integrated schedule is then used to generate an exhaustive set of reports detailing the science observations for each investigation, the resource usage (e.g., SSR and downlink), and instrument and guidance and control command requests in formats suitable for direct use by mission operations tools.

Reports and statistics are evaluated for every investigation and used to assess margins relative to project requirements and conduct reviews of revisions to the observation plan. For instance, monochrome coverage obtained by MDIS is shown in Figure 2 in the form of pixel resolution over the surface of Mercury. Complete schedules, rule violation reports, command requests, guidance and control commands, and predicted attitude quaternions are generated for each simulation run. Each run requires two to three hours of computer time and will be used to support observation plan adjustments in orbit at Mercury.

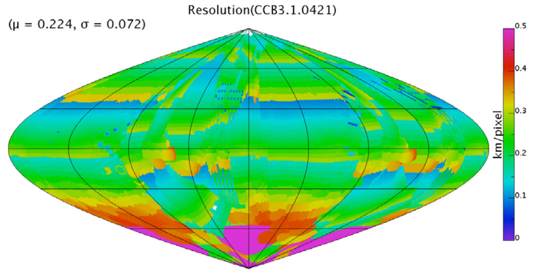

Figure 2. MDIS pixel resolution for the monochrome mapping observations. The average resolution is 224 m/pixel, and more than 96% of the planet is mapped.

References: [1] Leary J. C. et al. (2007) *Space Sci. Rev.*, *131*, 187-217. [2] Solomon S. C. et al. (2001) *Planet. Space Sci.*, *49*, 1446-1465. [3] Gold, R. E., et al. (2001) *Planet. Space Sci.*, *49*, 1467-1479.