

# Prometheus's Challenge: Scheduling MASCS Observations Using SciBox for Orbital Operations at Mercury

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Performing scientific observations of a planet from orbit is a complicated endeavor for a spectrograph with a small field of view. Adding in a second spectrometer with a different field of view, and attempting to observe three different aspects of the planet with a total of five detectors, constrained by severe orbital, pointing, and downlink limitations, increase the challenge. On board the MESSENGER spacecraft, the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), which consists of two separate instruments (the Visible and Infrared Spectrograph – VIRS – and the Ultraviolet and Visible Spectrometer – UVVS), will be facing precisely that challenge during the orbital operation phase of the mission to Mercury. As the cruise operations and three successive flybys of Mercury have demonstrated, manually sequencing observations for these two instruments is a labor-intensive task. In order to help schedule MASCS observations of both the surface and the planetary exosphere more efficiently, a planning tool called SciBox will be employed to generate the initial observation suite for each orbital period and coordinate MASCS observations with the other science instruments aboard the spacecraft.

## I. Introduction

Space missions have typically and traditionally used a labor-intensive approach to manually generating command loads to schedule science observations and execute daily spacecraft operations. This approach demands a great deal of time from the scientists, engineers, and sequencers (or schedulers) who must generate and review the instrument and spacecraft command loads by hand. As spacecraft and instrumentation become more complex and science goals ever more ambitious, the limits of manual scheduling and commanding are reached or exceeded. It becomes more necessary to turn to automated tools in order to efficiently generate the initial schedule and commanding and optimize science returns.

The Mercury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft is the first mission to visit the planet Mercury since the Mariner 10 performed three flybys of the planet in the mid-1970s. To date MESSENGER has performed three flybys (two in 2008, one in 2009) of Mercury. In March 2011 it will be the first spacecraft to go into orbit about Mercury. During the orbital phase of the mission, MESSENGER's suite of instruments will be working in concert to collect enormous amounts of information heretofore unknown about Mercury.

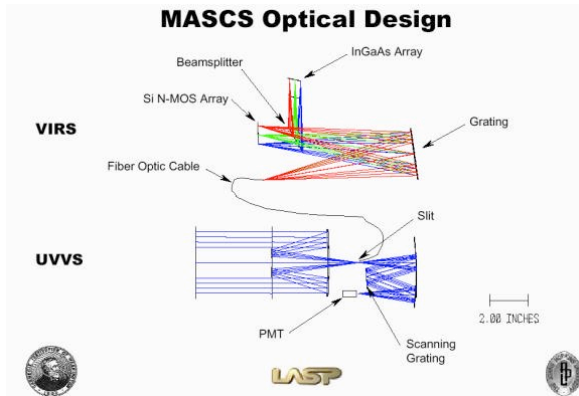


Figure 1: MASCS optical system schematic. For simplicity, only one photomultiplier tube (PMT) for the UVVS is shown.

## II. MASCS

The Mercury Atmospheric and Surface Composition Spectrometer<sup>1</sup> (MASCS) is one of eight science packages onboard the MESSENGER spacecraft. It is designed to determine the mineral composition of Mercury's surface as well as map out the species that are found in Mercury's exosphere. In addition it will aid in understanding the connections between the surface materials and the composition of the exosphere.

MASCS consists of a small Cassegrain telescope with an effective focal length of 257-mm and a 50-mm aperture that simultaneously feeds two separate instruments: the Ultraviolet and Visible Spectrometer (UVVS) and the Visible and Infrared Spectrograph (VIRS) (Figure 1). Each instrument has its own configuration and operational constraints and parameters.

The UVVS instrument (Figure 2) is a 125-mm focal length, scanning grating, Ebert-Fastie monochromator equipped with three photomultiplier tube (PMT) detectors that cover far ultraviolet (115-180 nm), middle ultraviolet (160-320 nm), and visible (250-600 nm) wavelengths with an average 0.6-nm spectral resolution. The grating drive mechanism can step through a spectral scan profile with a 1-arcminute accuracy, rotating over a range of approximately 45°. The UVVS also contains a slit mask mechanism that can adjust the slit dimensions to enable either bright surface or dim exospheric limb observations. UVVS measures the altitude profiles of known species in order to determine the composition and structure of Mercury’s exosphere and its variability and will search for previously undetected exospheric species.

The VIRS instrument (Figure 2) is a 210-mm focal length, fixed-concave-grating spectrograph equipped with a beam splitter that simultaneously disperses the spectrum onto a 512-element silicon visible photodiode array (300-1050 nm) (visible or VIS) and a 256-element indium-gallium-arsenide infrared photodiode array 850-1,450 nm (near-infrared or NIR). The photodiode arrays are illuminated by a fiber optic pickoff from the main UVVS telescope. Each photodiode array has an incandescent stimulus lamp to produce flat-field spectra for calibration purposes. The VIRS also has a shutter mechanism to shut off incoming light from the telescope when taking dark spectra. VIRS will obtain maps of surface reflectance spectra with a 5-nm resolution in the wavelength range 300-1,450 nm that will be used to investigate mineralogical composition on spatial scales of 5 km. UVVS will also observe discrete targets on the surface in the ultraviolet to visible at a 10-km or smaller spatial scale.

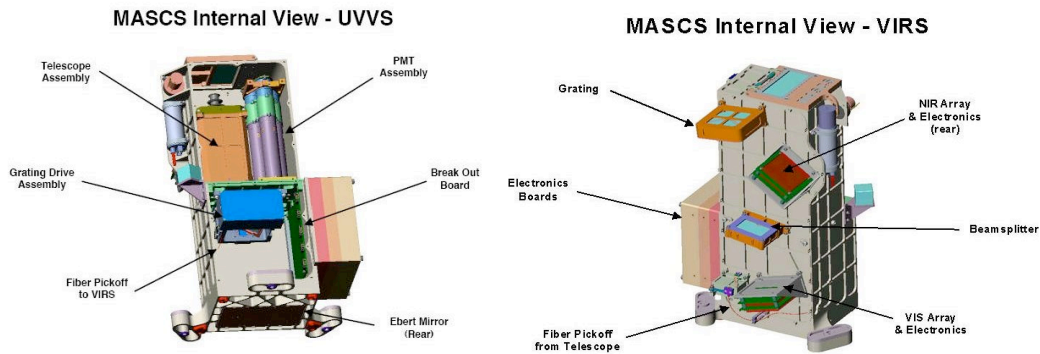


Figure 2: Solid-model drawings illustrating the internal views of the UVVS and VIRS instruments.

### III. Commanding MASCS

As with the other instruments on MESSENGER, the MASCS instruments are commanded using ground and flight-tested, reusable command blocks<sup>2</sup>. These command blocks are built from canned activity sequences (CASs) and fragment protocols (fragments). Fragments call bare spacecraft and instrument commands and can set individual parameters such as the integration times. CASs do not call bare spacecraft commands, but rather one or more fragments. The CAS commands are then assembled in a spacecraft activity sequence file (SASF), which is used to generate the final command sequence executed by the instrument.

The VIRS instrument is relatively simple to command. A handful of CASs are used to execute all the planned observations and other instrument activity. In the case of UVVS operations, however, the final command load contains tens, hundreds, and even thousands of looped CASs, with the parameters being reset for each loop iteration. It is inefficient to command manually the instrument in this manner with so many looped CASs. Thus macros were developed. Macros contain one full loop of CASs for the instrument to execute. If tens or even thousands of loops are required for a desired observation, the macro is set to execute for a given time duration to ensure that the full amount of data is captured. It is much more efficient to set a macro to loop  $n$  times than it would be to issue the CAS calls over and over. Thus a given macro may contain 64 CAS calls and require 40 s to perform one iteration. If a particular observation requires 2 hours of time, that would require the set of CASs to be repeated 75 times. Instead of manually entering the 64 CAS lines 75 times, it is much easier and more efficient to execute a single macro for a duration of 2 hours. As of the writing of this paper there are over 50 macro sequences for the UVVS.

Each macro is designed to observe an emission range of one or more exospheric species. Macros designed to observe single species (such as hydrogen or potassium) do not scan over large sections of the grating drive, but dwell in only narrow wavelength ranges. These macros are known as “single-scan” macros, as they only have one set of commands and parameters that are looped. Macros designed to observe two or more species are “multi scan”

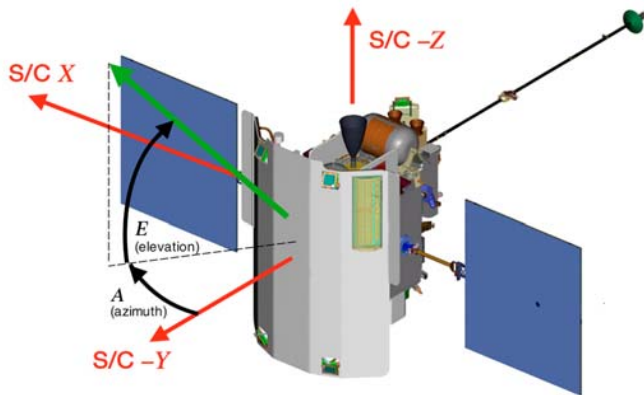
macros, and thus have to cover more range on the grating drive in order to cover more wavelength regions for species detection.

#### IV. Orbital Observational Challenges

MESSENGER has a number of highly restricting constraints under which it will have to operate while in orbit about Mercury<sup>2-5</sup>. These constraints, all of which must be taken into account, drive the science observation planning as well as the day-to-day operations of the spacecraft.

##### A. Pointing Limitations

Due to the extreme temperature and solar radiation that MESSENGER will experience at Mercury, the spacecraft has been outfitted with a ceramic-fabric sunshade measuring 2.4 by 1.8 m. The sunshade, which is made from the same materials that protect sections of the Space Shuttle and the International Space Station, will keep the spacecraft and payload at a nominal operating temperature of 20-25°C. However, as seen in



**Figure 3. Illustration of the MESSENGER orientation axes. The instrument boresight is along the +Z axis. The sunshade is in the -Y direction, and the main thruster is in the -Z axis.**

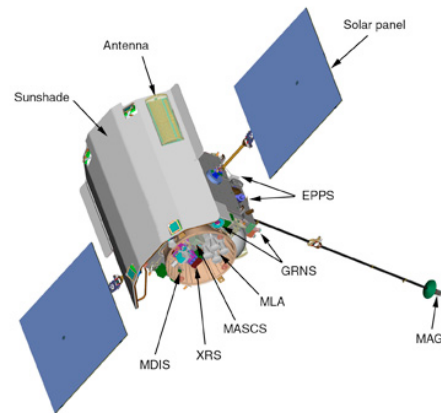
Figure 3, the sunshade does not fully envelop the spacecraft, so MESSENGER must constantly keep the sunshade between itself and the Sun. Called the Sun-keep-in (SKI) limit, this requirement tightly constrains the pointing of the spacecraft, as it may rotate no more than 10-12° off of the Sun-spacecraft axis. This in turn means that MESSENGER's instrument suite, for the most part boresight-pointed in the +Z axis, are similarly restricted in that they may not point further than 10-12° off the right angle to the sunshade-Sun (-Y) axis.

##### B. Conflicting Science Observations

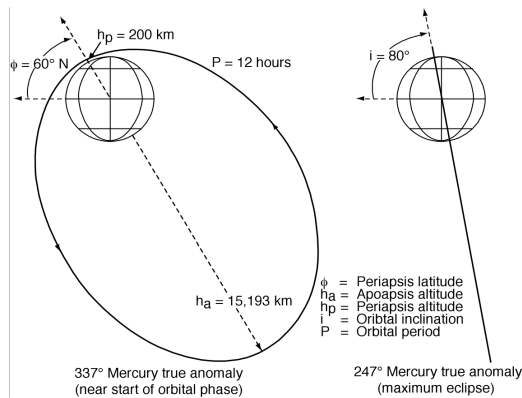
As noted earlier, MESSENGER has a suite of eight science instruments. Most of the time these instruments will operate in concert with one

##### C. Variable Downlink Opportunities

another, but there will be times when certain observations will favor one instrument over all the others. This is complicated by the fact that all the instruments (except the cameras of the Mercury Dual Imaging System or MDIS) are mounted to point along the +Z axis (the MDIS has a pivot arm that allows it limited freedom to point from -40 to +50° in the Y-Z plane), as illustrated in Figure 4. For example, one of the mandates of the MASCS instrument is to examine the exosphere above the surface of Mercury. The only times that this is possible are the limited opportunities in each orbit to shift the boresight pointing from directly at the planet to along the limb.



**Figure 4. Solid model drawing indicating the relative positions of the science instruments as well as the solar panels and the sunshade.**



**Figure 5. MESSENGER's orbital orientation around Mercury**

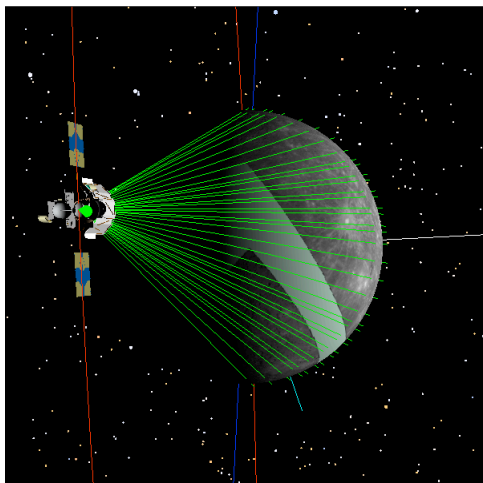
observations.

Mercury's orbit and rotation will limit observation opportunities by MESSENGER's science instruments. Mercury has a rotational period of 56 days and orbits the Sun every 88 days. In a 3:2 spin-orbit resonance, Mercury has a solar day that is 176 Earth days long. MESSENGER's orbital plane will be approximately fixed in inertial space, which means that viewing opportunities for a given angle to any given location on the surface will repeat only once every 176 days. Figure 6 shows Mercury's orbit about the Sun with MESSENGER's inertially fixed orbit about Mercury. Positions 1 and 2 are noon-midnight orbits for MESSENGER (meaning that the orbital track crosses over the noon and midnight regions of Mercury), and positions 3 and 4 are the dawn-dusk orbits (where MESSENGER's orbit rides along the terminator).

Complicating the above, the SKI limits noted earlier impose further pointing restrictions on the spacecraft's instruments. The end result is that the majority of the observations made will rarely have on-nadir pointing.

### E. Power Constraints

Being so near the Sun, MESSENGER is powered by solar panels and batteries charged from the solar arrays. It does not carry a separate power generation unit. Because of the precessing nature of the orbit relative to Mercury and the Sun, there are periods when MESSENGER will be in eclipse and will rely solely on the batteries for power. Since the power requirements to operate the spacecraft and its payload draw more power than can be provided from the batteries, the eclipse periods (followed by a short interval after exiting eclipse in which the batteries recharge from the solar panels) are times of minimal power usage. The science instruments are not powered during these times.

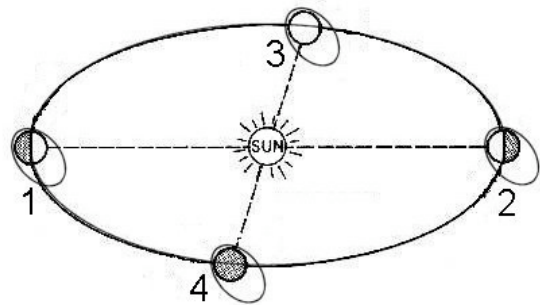


**Figure 7. Limb-scan pointing opportunities for exosphere observations**

of Mercury. This restriction would strongly impact observation opportunities of Mercury's surface or exosphere. Given that the solid-state recorder does not have an infinite capacity to store data, operating under such highly variable downlink opportunities and constraints means that great care must be taken in scheduling science observations so that the recorder does not overflow, and that downlink opportunities minimally impact observations.

### D. Complex Observing Geometries

As can be seen in Figure 5, MESSENGER's 12-hour nearly polar orbit around Mercury will be highly elliptical, with elevation ranging from 200 kilometers at apoapsis to over 15,000 kilometers at periapsis. The surface track speeds will range from 3.7 km/s to 0.6 km/s, respectively. Thus both orbital velocity and planet distance will need to be considered when scheduling



**Figure 6. Mercury's orbit about the Sun, and the two noon-midnight (positions 1 & 2) and dawn-dusk (positions 3 & 4) orbits of MESSENGER**

### F. MASCS Complications

The MASCS instrument introduces additional complications not only to other instruments on MESSENGER, but to itself. First, while MASCS uses one telescope to gather light for its instruments, due to the fiber optic pick-off cable the effective boresights of the UVVS and VIRS are not identical, but rather are separated by  $0.38^\circ$  in the X-Z plane. Thus the two instruments cannot simultaneously observe the same location on the planet.

In addition, MASCS is a self-conflicted instrument. The VIRS instrument is designed for surface observations, whereas the UVVS,



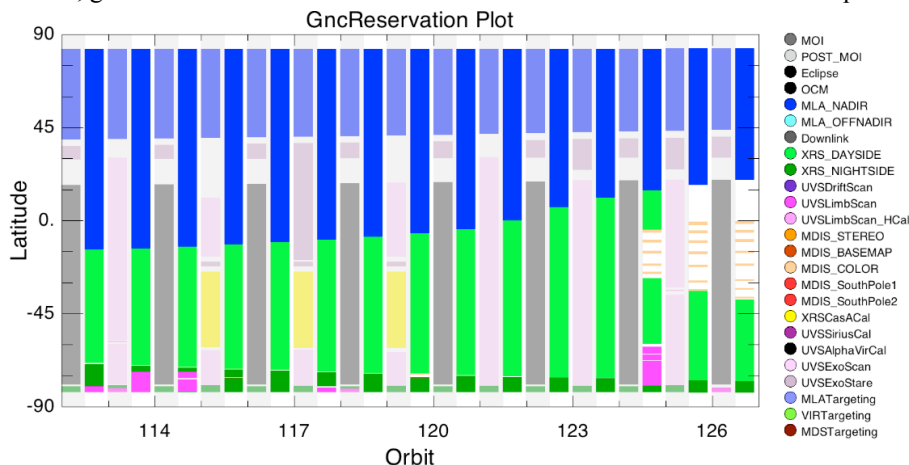
while capable of taking surface observations, is the only instrument designed to study Mercury’s exosphere, and thus must point away from the surface and along or just above the limb of the planet (Figure 7) or across Mercury’s “tail.” The UVVS exosphere observation requirements can often come into conflict with those for most of the rest of MESSENGER’s science instruments, most of which are designed only for surface observations. This conflict adds to the challenge of meeting all the science requirements of the mission, as well as additional challenges to scheduling observation opportunities.

## V. MESSENGER SciBox

Developed at the Johns Hopkins University Applied Physics Laboratory (JHUAPL), MESSENGER SciBox is an integrated goal-based planning and commanding system that is based on SciBox, a Java-based software library<sup>3,4,6</sup>. MESSENGER SciBox contains visualization packages to support exploratory operations concepts, scheduling packages for saving and interacting with abstract science operations, and geometry and event analysis packages for rapid analyses of observational opportunities.

An early version of the goal-based planning and commanding system based on SciBox was first deployed and used by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on the Mars Reconnaissance Orbiter (MRO) mission<sup>4,5</sup>. This version of SciBox had only one instrument to schedule, but it successfully demonstrated improved planning and scheduling efficiency that optimized science return as well as improved the overall efficiency of the spacecraft operations.

The MESSENGER version of SciBox is based on the CRISM version<sup>3</sup> but is far more capable. Taking into account all the constraints and limitations that will be imposed on MESSENGER during orbital operations (covered in Section IV), MESSENGER SciBox is now capable of generating the detailed preliminary schedule of observations for multiple instruments on board the spacecraft. Ideally the preliminary schedule will be the most efficient possible, given the orbital observation constraints and the various instrument requirements.



**Figure 8.** A SciBox output plot illustrating the instrument that is dominant with guidance and control pointing. The dark blue bars indicate MLA nadir pointing. The pink bars indicate UVVS limb-scan opportunities. This plot does not model time linearly.

Stepping away from the manually generated schedule paradigm, MESSENGER science teams will exclusively use MESSENGER SciBox (hereafter SciBox) to analyze observation opportunities and schedule science observations. Manual optimization of science plans is possible, constrained by the limitations outlined earlier. Instrument and guidance and control (G&C) commands are automatically generated when the observation schedules are completed and converted to SASFs.

Figure 8 shows the instruments that control the guidance and control pointing for orbits 112 through 127. During this period, the Mercury Laser Altimeter (MLA) has pointing control (indicated by the dark blue bars) while the spacecraft is over northern Mercury latitudes for ranging surface observations. The powder blue bars are for specific MLA targeting opportunities. The light green indicates that the X-Ray Spectrometer (XRS) has pointing control. The few instances of pink bars indicate opportunities that the UVVS instrument would be scheduled to control the spacecraft pointing for limb-scan observations.

Note that no instrument dominates for an entire orbit. As only one instrument at a time may control the spacecraft pointing, all other instruments may observe in a ride-along mode. This means that if they have an

opportunity to perform any observations they will be powered on and taking data, but they will be at the mercy of whichever instrument has been given the guidance and control.

### VI. The SciBox/MASCS Challenge

The first challenge SciBox needs to address with MASCS is identical to that of all the other instruments: when are the best opportunities for it to perform observations? The difference from the other instruments is that MASCS is essentially two instruments bundled into one, with occasional conflicting observation requirements.

During orbital operations, the MASCS science and sequencing team will employ a two-phase process<sup>2</sup> to plan and coordinate MASCS observations. The first phase is the Advance Science Planning (ASP) process, which begins 8 weeks prior to the commands being sent to the spacecraft. In the ASP process, SciBox is employed to schedule VIRS mapping and targeted observations, UVVS dayside limb scans, UVVS polar scans, UVVS exosphere tail scans, UVVS interplanetary hydrogen background measurements, and UVVS/VIRS star calibrations based on the latest trajectory predictions and available DSN tracks. These observations are scheduled in priority order<sup>3</sup> assigned by the project. The output of the ASP cycle is an optimal deconflicted observation plan for the rest of the mission. The observation plan and historical coverage are overlaid on top of each other to provide mission status monitoring as well as long-term strategic planning. During the second phase, two weeks before commands for the planned observations are uplinked, the MASCS team will use SciBox to amend individual observations by increasing or decreasing spectral resolution sampling pending more accurate near-term predictions of available SSR space and downlink bandwidth.

As the VIRS instrument will infrequently take pointing control, except for occasional special targeted areas on the surface, it is primarily a ride-along instrument. The SciBox developers had to imbue SciBox with enough intelligence to understand when the best times for performing VIRS targeted observations occur, and which, if any, other instruments that are also interested in the same target will have an opportunity to take similar data. This was one of the fundamental challenges for SciBox, as all instruments shared this conflict. Figure 8 illustrates a typical schedule of VIRS commands. The standard scans are ride-along observations while another instrument retains the pointing control, and the targeted activities are VIRS targeted scan opportunities, where VIRS retains pointing control. These targeted opportunities, as can be seen in Figure 9, are brief, lasting a few tens of seconds.

| Start Time UTC        | Stop Time UTC     | VIRS Mode               | Comments |
|-----------------------|-------------------|-------------------------|----------|
| 2011 165T18:10:03.135 | 2011 165 19:12:42 | VIRS Stdrd Scan w Setup |          |
| 2011 166T01:58:26.406 | 2011 166 01:59:33 | VIRS Stdrd Scan w Setup |          |
| 2011 166T02:24:28.146 | 2011 166 02:24:49 | VIRS Stdrd Scan w Setup |          |
| 2011 166T02:24:50.848 | 2011 166 02:25:37 | VIRS Targeted Activity  |          |
| 2011 166T02:33:44.589 | 2011 166 02:34:18 | VIRS Stdrd Scan w Setup |          |
| 2011 166T02:34:19.524 | 2011 166 02:35:06 | VIRS Targeted Activity  |          |
| 2011 166T02:35:28.524 | 2011 166 02:35:40 | VIRS Stdrd Scan w Setup |          |
| 2011 166T02:42:13.784 | 2011 166 02:43:03 | VIRS Stdrd Scan w Setup |          |
| 2011 166T02:43:04.579 | 2011 166 02:43:51 | VIRS Targeted Activity  |          |
| 2011 166T02:44:13.579 | 2011 166 02:44:41 | VIRS Stdrd Scan w Setup |          |
| 2011 166T02:58:22.112 | 2011 166 02:59:09 | VIRS Stdrd Scan w Setup |          |
| 2011 166T02:59:10.162 | 2011 166 02:59:57 | VIRS Targeted Activity  |          |
| 2011 166T03:00:19.162 | 2011 166 03:04:51 | VIRS Stdrd Scan w Setup |          |
| 2011 166T03:04:52.525 | 2011 166 03:05:39 | VIRS Targeted Activity  |          |
| 2011 166T03:06:01.525 | 2011 166 03:11:55 | VIRS Stdrd Scan w Setup |          |
| 2011 166T03:52:56.721 | 2011 166 03:55:04 | VIRS Stdrd Scan w Setup |          |

Figure 9. The SciBox VIRS Editor display showing the two basic observation types (standard scan or targeted activity)

UVVS adds to the complexity of MESSENGER scheduling. UVVS has requirements to point at Mercury's surface and has a controllable slit mask in its aperture to compensate for the high signal levels from the bright surface. But in its principal role, it was designed to examine the rarefied exosphere surrounding Mercury, which requires pointing opportunities very different from those of the other instruments. In addition to this, the UVVS has the capability of examining a wide range of wavelengths from the far ultraviolet to the visible light spectrum.

However, due to the design of the spectrometer, it cannot scan the entire wavelength range at the same time with all three PMTs powered (i.e., only 2 PMTs at a time, scanning over the grating one wavelength at a time). So to cover all scientifically interesting wavelength regions to which each PMT is sensitive to, as of this writing, over 50 macros have been developed for UVVS.

The state of Mercury’s exosphere is both spatially and temporally highly variable. Given this variability, UVVS

Filter: 2011 077T22:54:00.299–2012 085T01:04:32.610

| Start Time UTC    | Stop Time UTC     | Operation       | Macro Called                   | Macro Table                 | Macro Table... |
|-------------------|-------------------|-----------------|--------------------------------|-----------------------------|----------------|
| 2011 085 01:47:56 | 2011 085 01:54:57 | UVVSLoopedMacro | MAS_MSS_SII-SiII_FME_1_SURF    | table4_exosphere_mapping... | 13             |
| 2011 085 17:34:04 | 2011 085 17:41:05 | UVVSLoopedMacro | MAS_MSS_H_FFE_1_SURF           | table4_exosphere_mapping... | 15             |
| 2011 086 01:44:05 | 2011 086 01:51:06 | UVVSLoopedMacro | MAS_MSS_H_FFE_1_SURF           | table4_exosphere_mapping... | 15             |
| 2011 086 17:29:20 | 2011 086 17:36:21 | UVVSLoopedMacro | MAS_MSS_OH-Al_VVE_1_SURF       | table4_exosphere_mapping... | 17             |
| 2011 087 01:39:21 | 2011 087 01:46:22 | UVVSLoopedMacro | MAS_MSS_OH-Al_VVE_1_SURF       | table4_exosphere_mapping... | 17             |
| 2011 087 17:27:30 | 2011 087 17:34:31 | UVVSLoopedMacro | MAS_MSS_Ca_VVE_1_ATMO          | table4_exosphere_mapping... | 19             |
| 2011 088 01:37:31 | 2011 088 01:44:32 | UVVSLoopedMacro | MAS_MSS_Ca_VVE_1_ATMO          | table4_exosphere_mapping... | 19             |
| 2011 088 17:26:38 | 2011 088 17:33:30 | UVVSLoopedMacro | MAS_MSS_C-AllI-MgII_FVE_1_ATMO | table4_exosphere_mapping... | 21             |
| 2011 089 01:36:30 | 2011 089 01:43:31 | UVVSLoopedMacro | MAS_MSS_C-AllI-MgII_FVE_1_ATMO | table4_exosphere_mapping... | 21             |
| 2011 089 17:26:40 | 2011 089 17:32:54 | UVVSLoopedMacro | MAS_MSS_Fe_VVE_1_ATMO          | table4_exosphere_mapping... | 23             |
| 2011 090 01:35:54 | 2011 090 01:42:55 | UVVSLoopedMacro | MAS_MSS_Fe_VVE_1_ATMO          | table4_exosphere_mapping... | 23             |
| 2011 090 17:26:55 | 2011 090 17:32:34 | UVVSLoopedMacro | MAS_MMS_PHYSICAL-A2_MVX_4      | table4_exosphere_mapping... | 25             |
| 2011 091 01:35:34 | 2011 091 01:42:35 | UVVSLoopedMacro | MAS_MMS_PHYSICAL-A2_MVX_4      | table4_exosphere_mapping... | 25             |
| 2011 091 17:27:20 | 2011 091 17:32:24 | UVVSLoopedMacro | MAS_MSS_K_VVE_1_ATMO           | table4_exosphere_mapping... | 27             |
| 2011 092 01:35:24 | 2011 092 01:42:25 | UVVSLoopedMacro | MAS_MSS_K_VVE_1_ATMO           | table4_exosphere_mapping... | 27             |

**Figure 10. The SciBox UVVS Editor showing a sampling of different macros being scheduled for exospheric observations. The rightmost column is the Macro Table Line Number.**

observations must be flexible and adaptable in-orbit as the situation and circumstances dictate. The MASCS team has generated a suite of UVVS observation tables that contain one or more macros appropriate for a specific scenario. As of January 2010, the MASCS team had identified a dozen observation scenarios, which include scenarios in which UVVS has pointing control (such as exosphere mapping scans, polar scans, and radial limb scans) and those in which it does not (i.e., ridealong observations or opportunities, such as downlink period scans, night-side opportunity scans, and limb-opportunity scans).

Given a particular observation scenario, SciBox will select the appropriate table and cycle through the macros within the table. Once SciBox has cycled through a given table, it loops and recycles through it again.

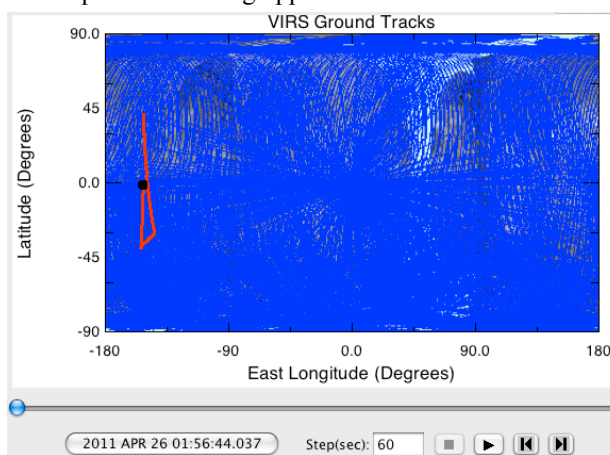
As the mission evolves, the MASCS science team will learn more of the make-up of Mercury’s exosphere. They will also learn which macros were most useful and which proved to be ineffective. The team has the capability of regenerating the tables, swapping macros around, or even completely out, by replacing the deleted ones with new macros. The tables would then be redelivered to SciBox for subsequent scheduling opportunities.

Figure 10 shows an example of the exosphere mapping scenario, and some of the macros that might be called for that scenario. Note that macros are not confined to a specific table and may also be used in other observing scenarios.

### VII. SciBox MASCS Analysis Tools

SciBox has a suite of display tools that the MASCS science team can use in order to understand the predictive schedule SciBox has generated for upcoming observations, and whether or not it might be necessary to change manually the schedule from the one SciBox generates.

Because the VIRS instrument primarily rides along when other instruments are in control of the G&C pointing, its observation track is relatively straightforward most of the time. The VIRS ground track display (Figure 11) illustrates the latitude and longitude where the VIRS scans run over the surface of Mercury for a given time period. However, “riding along” with other instruments, such as the XRS or MLA, can result in



**Figure 11. The time displayed VIRS ground track in red illustrating a change in direction of the boresight pointing**

complicated patterns of where the VIRS boresight is pointed with respect to Mercury’s surface. During the times when another G&C-controlling instrument needs to point the boresight to another section of the planet’s surface, the VIRS ground track will jump, travel in an orthogonal direction to what might be expected, or even perform loops.

The latitude and longitude axes in Figure 11 correspond to Mercury coordinates. The planetary map is obscured as the display shows all of the VIRS boresight ground tracks for the entire mission. As of this writing, the capability to toggle on or off all of the VIRS boresight ground tracks has not yet been implemented into SciBox.

Unlike VIRS and most of the other instruments on board MESSENGER, the UVVS has more pointing control requirements. As described in section IV-B, in addition to targeted surface observations, UVVS will be doing detailed exploration of Mercury’s exosphere. This includes scanning the “tail” region behind Mercury with respect to the Sun, performing limb scans (observations just above the limb of the planet; see also Figure 7), and polar scans, which are a specialized subset of limb scans that focus exclusively on the Mercury polar regions.

Limb scans themselves are designed to map the exosphere of Mercury. There are three basic types of limb scans: dayside radial, surface-connected and polar. Opportunities for executing limb scans vary depending on the relative orientation of the spacecraft’s orbit with respect to the Sun and Mercury, as well as what other activities may take priority over exosphere scans. These other activities include surface-pointed science observations of the planet as well as general spacecraft activities such as downlink. Figure 12 shows the exosphere scan opportunities (blue) versus downlink times (green). The red bar is the exosphere scan opportunity for the noted time as calculated by SciBox.

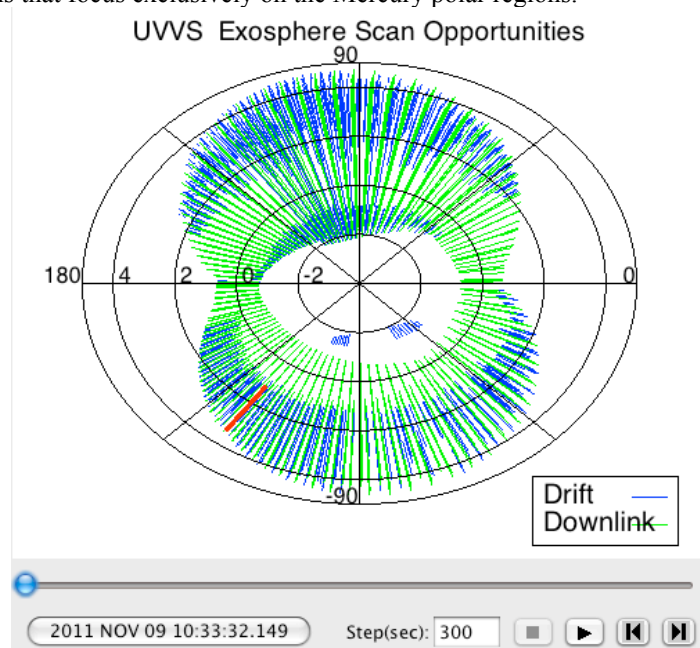


Figure 12. Exosphere Scan Opportunities interleaved with spacecraft downlink periods for the first year of the mission10.

Dayside radial limb scans are intended to probe the radial distribution of species in the exosphere on the dayside of Mercury. These limb scans range from 50 km above Mercury’s surface to between 500 and 5000 km above the surface, depending upon the species that is being mapped. Figure 13 illustrates the low and extended limb-scan schemes. The low and extended modes may be interleaved for a combination of high and low scans in one observation opportunity.

Surface-connected limb scans are a special case of the dayside radial limb scans. Surface-connected scan mode occurs when the ground track of a normal daylight radial limb scan (the subscan track) passes through a surface area defined by a range of latitude and longitude points. SciBox is able to evaluate whether or not a daylight radial limb scan should be performed instead of a surface-connected scan, and to execute the appropriate macro(s) as defined by the MASCS science team.

Figure 14 shows the subspacecraft and subscan tracks for surface-connected scans over Mercury. The black lines

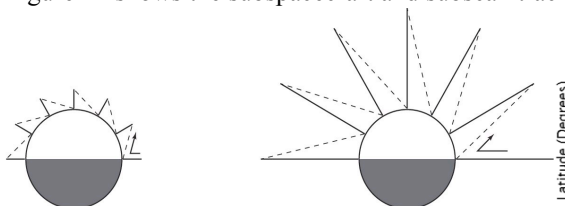


Figure 13. Two types of dayside radial limb scans. The observations begin at high altitude and scan down towards the planet, stopping at about 50 km above the surface. The boresight is then redirected up to the upper altitude and the scan resumed.

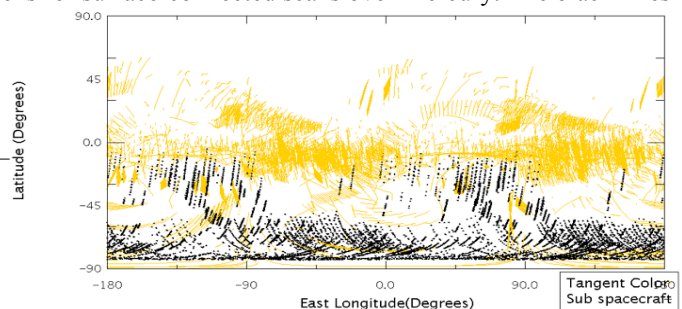


Figure 14. Latitude and longitude locations of the subspacecraft and subscan points during UVVS limb-scans



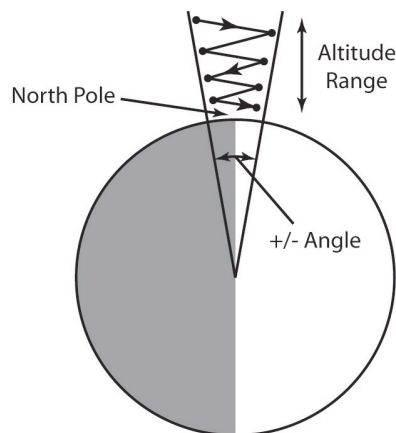
represent the nadir point of the spacecraft at the time of a specific surface-connected scan. The yellow lines are the surface subscan tracks directly below where the limb scan is being taken with respect to the surface of Mercury. As can be seen, the vast majority of the limb scan observations will be performed over the equatorial regions of Mercury.

Polar scans are specialized limb-scan sequences that are designed to explore the exospheric regions over the poles, where the permanently shadowed portions of Mercury’s surface may contain volatiles of particular interest to the science team. However, due to the spacecraft SKI constraints (described in section IV-A), the only orbits where these observations are practical are those nearest the dawn-dusk configuration. But because these particular orbital configurations are of high priority for all pointed instruments owing to the ability to see the illuminated disk at all times, there will be only limited opportunities to conduct polar scans. Therefore polar scans are designed to provide the maximum coverage over the polar regions in the minimum time.

Figure 15 illustrates a polar scan sequence for the inbound north pole portion of the orbit. The scan would begin at high altitude and zigzag down to just over the surface, with the scan going  $\pm 3^\circ$  to either side of the pole. On the outbound portion of the orbit, the scan would be reversed, starting low and ending high.

SciBox performs all the necessary G&C calculations for these scans, as well as the observation duration, and would consult the polar-scan-specific table in order to determine which macro to utilize. Figure 16 shows the SciBox calculations of start and stop times for a polar scan, the duration of the scan, the pole the observation will cover, the scan type, and the macro to be used.

Assisted by these scheduling analysis tools, the science team during orbital operations will have the opportunity to examine data already taken and compare them both to the observations just made and to the observations SciBox will be scheduling. The team can then best understand whether or not to adjust the tables or to follow on the schedule suggestion that SciBox calculates. This capability allows flexibility for the team in searching for different volatiles during orbital operations.



**Figure 15. Inbound north polar scan illustration**

| Start Time UTC    | Stop Time UTC     | Duration | Scan Pole | Sca... | Macro |
|-------------------|-------------------|----------|-----------|--------|-------|
| 2011 210 16:58:07 | 2011 210 17:30... | 00:32:21 | South     | Scan   | 33    |
| 2011 210 17:54:16 | 2011 210 18:22... | 00:28:19 | North     | Scan   | 33    |
| 2011 253 04:10:39 | 2011 253 04:43... | 00:32:21 | South     | Scan   | 28    |
| 2011 253 05:09:34 | 2011 253 05:41... | 00:32:21 | South     | Scan   | 28    |
| 2011 298 16:40:37 | 2011 298 17:12... | 00:32:21 | South     | Scan   | 8     |
| 2011 298 17:37:49 | 2011 298 18:10... | 00:32:21 | South     | Scan   | 8     |
| 2011 298 18:31:42 | 2011 298 19:04... | 00:32:21 | North     | Scan   | 8     |
| 2011 340 17:06:15 | 2011 340 17:38... | 00:32:21 | South     | Scan   | 9     |
| 2011 340 18:02:26 | 2011 340 18:34... | 00:32:21 | South     | Scan   | 9     |
| 2011 340 19:00:05 | 2011 340 19:32... | 00:32:21 | North     | Scan   | 9     |
| 2011 340 19:43:35 | 2011 340 20:15... | 00:32:21 | South     | Scan   | 9     |
| 2012 020 17:20:22 | 2012 020 17:52... | 00:32:21 | South     | Scan   | 33    |
| 2012 020 18:14:52 | 2012 020 18:47... | 00:32:21 | South     | Scan   | 33    |
| 2012 063 05:19:31 | 2012 063 05:51... | 00:32:21 | South     | Scan   | 28    |
| 2012 063 06:13:08 | 2012 063 06:45... | 00:32:21 | South     | Scan   | 28    |

**Figure 16. A SciBox-generated table of polar scan opportunities**

### VIII. Summary

Scheduling observations with the MASCS science package would be a daunting proposition for the sequencing team to undertake without capable software assistance. The MESSENGER SciBox tool will prove to be an invaluable asset not only in creating schedules, but also giving an understanding to the sequencing team as to the nature of the observations. It will also be used by the mission operations team to examine the long-term strategic mission planning in order to make efficient short-term commanding. During the final cruise phase prior to orbital operations, MESSENGER SciBox will be undergoing final refinements that will better assist both the sequencing and science teams with their observation planning and scheduling.

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