Mercury Scout: mapping Mercury's mineralogy.

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Introduction: Mercury Scout is a low-cost, SmallSat mission concept that has two main goals: 1) map the mineralogy of Mercury's surface using the 4-8 micron spectral region and 2) image selected areas at 1-meter spatial resolution at visible wavelengths. Combined, these two data sets will fill fundamental knowledge gaps, provide new insights into Mercury's evolution and provide key information for selecting sites for future landed missions. To keep the mission cost low, and extend the orbit duration, we use a solar sail as the primary propulsion system, similar in size to that of the selected Solar Cruiser mission.

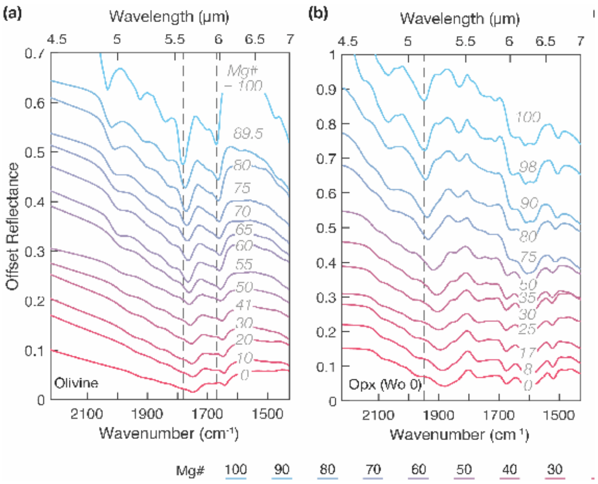

Figure 1. *IMIR spectra of olivine (left) and orthopyroxene (right), as a function of composition. Note the shift and increase in band depth with higher Mg contents [1].*

Science Goal 1 - Mineralogy: Due to the low Fe content of the silicate minerals on Mercury, the VNIR spectrometer on the MESSENGER mission was not able to identify or map the surface mineralogy. As this was one of the primary science goals, it represents a first-order knowledge gap in Mercury science. Recently, the 4-8 micron spectral range (IMIR = **I**nter**M**ediate **I**nf**R**ared) has been shown to have bands that are diagnostic of olivine, orthopyroxene, clinopyroxene and plagioclase feldspar (Fig. 1; [1]). Importantly, the IMIR bands do not require Fe to be present, and are in fact stronger at lower Fe contents. The band positions shift with composition, and so they can also be used to estimate mineral chemistry remotely. See abstract by Kremer et al (this meeting) for more information on IMIR spectroscopy.

Mapping the mineralogy of Mercury's surface would allow a range of fundamental questions to be addressed, including:

1) What is the origin of high-magnesium region (HMR; Fig. 2; [2])? Is it a very mafic lava, or is it a part of the mantle brought to the surface? The ol/opx ratio of the HMR would greatly constrain the answer.

2) What is the fO_2 of Mercury? Most models suggest log fO_2 is 3 to 7 log units below the iron-wüstite oxygen buffer (IW -3 to -7)[3]. At these conditions, silicates are essentially Fe-free and should show no band shifts in the 4-8 micron region. If substantial band shifts are seen on Mercury, it would strongly imply $fO_2 >$ IW-3.

3) What is the nature of the low-reflectance material (LRM)? This is seen across much of Mercury's surface. Many craters appear to excavate it from depth. It also seems to be the material in which the enigmatic hollows form. Measuring its mineralogy would provide important evidence about its origin.

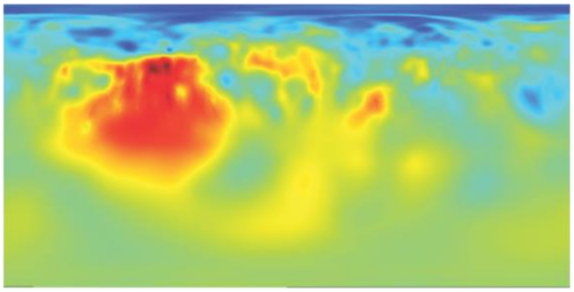

Figure 2. *Mg/Si ratio of surface as measured by XRS. The red (high Mg/Si) region is the HMR, which has no surface topography expression. Is this a large lava flow, like the northern smooth plains, or is it mantle exhumed by a large impact? Quantitative measurements of its mineralogy would help answer these questions. Map produced by QuickMap, after [2].*

Science Goal 2 – active surface processes Mercury's surface has a range of actively evolving features, including:

1) Hollows - these have few craters, implying a very young age. Comparison of repeated imaging of hollows appear to show active formation [4].

2) Craters - formed by meteorite impact show clear signs of degradation due to space weathering.

3) Faults – small-scale faults appear to be recently formed features, due to thermal contraction [5]. This implies strong planetary cooling, with large component

of the heat loss coming from the core. Fundamentally, this cooling is likely what drives the current magnetic dynamo. All of these features are not well resolved with the MESSENGER images, and will not be much better with Bepi-Columbo. High-resolution visible-light images with 1 meter spatial resolution would provide invaluable insights into active processes on Mercury's surface.

Science Goal 3 – polar volatile deposits: One of the most important discoveries of the MESSENGER mission was the presence of ice in permanently shadowed regions (PSRs) at the north pole [6]. High-resolution images of the PSR interiors would allow better estimation of their volume, distribution and temporal/thermal evolution.

Mission Duration: Both the mineralogy mapping and high resolution imaging would greatly benefit from long orbit durations. For the mineralogy, repeated spectra of the same area can be integrated to greatly improve signal-to-noise ratio. For the high-resolution imaging, the number of target areas can be increased proportional to the orbit duration. Third, for studying surface evolution, watching over longer durations will allow larger changes to be seen.

Instruments: To address the above science goals, we propose the mission incorporate three instruments: 1) IMIR spectrometer, 2) radiometer and 3) high-resolution, narrow-angle camera. Rob Green at JPL/CalTech is developing a HOTBIRD spectrometer to measure spectra in the 4-8 micron range, with 10nm sampling. It is similar in architecture to the HVM3 spectrometer to be flown on Lunar Trailblazer (Fig. 3). The radiometer is primarily to provide temperature-based corrections for the IMIR spectroscopy. The radiometer and visible camera designs and providers have not been chosen.

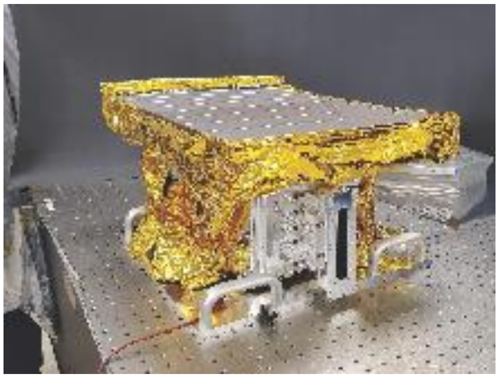

Figure 3.. *The Lunar Trailblazer HVM3 spectrometer design (above) can be coupled with a HOTBIRD 4-8 µm detector to enable unique sensing capabilities. Image JPL/CalTech.*

Propulsion: Getting to Mercury requires a high delta V. With standard propulsion, this requires long transit times, multiple planet gravity-assist breaking passes and short orbit durations. Solar sail propulsion is ideal for Mercury (Fig. 4). The ~10 times strong solar wind at Mercury (relative to Earth) allow direct trajectories. With no delta V from launch (e.g. rideshare), transit time is ~ 5 years, which can be cut down to <4 years with some delta V from launch. After arrival, it takes 52 days to get into a polar orbit and 150 days to complete one full mapping of the surface. Because the duration is not limited by fuel, as long as the satellite is functioning, the orbit can be maintained indefinitely, including elliptical orbits evolve their perigee position over time, to cover the whole planet. Demonstrating the use of solar sails for Mercury exploration would greatly benefit future missions, including landers and sample return missions.

Figure 4. *NEA Scout solar sail, unfolded in clean room. Image NASA, Emmett Given.*

Site selection for landed missions: The next major phase of exploring Mercury will center on landed missions. The sites for these missions should have the highest science value and lowest hazard. The mineralogical data from the IMIR spectrometer will provide key data for choosing the best science targets, while the high-resolution images will provide necessary resolution for hazard avoidance. Thus Mercury Scout will be a key step towards future landed missions. The short transit time provided by the solar sail would also allow timely acquisition of the data.

References: [1] Kremer et al. (2020) GRL 47(20) e2020GL089151. [2] Weider et al. (2015) EPSL 416: 109-120. [3] Zolotov et al. (2013) JGR Planets 118: 138-146. [4] Speyerer et al. (2022) GRL 49(16) e2022GL100783. [5] Watters et al. (2016) Nat Geoscience 9: 743-747. [6] Chabot et al. (2016) GRL 43: 9461-9468.