

MERCURY SCOUT: A SOLAR SAIL MISSION TO THE INNERMOST PLANET. S. W. Parman¹, J. F. Mustard¹, C. M. Pieters¹, C. H. Kremer^{1,2}, R. O. Green³, M. S. Bramble³ and L. Johnson⁴, ¹Brown University, ²Stony Brook University, ³JPL/CalTech, ⁴Marshall Spaceflight Center. (contact stephen_parman@brown.edu)

Introduction: Here we describe a low-cost orbital mission to Mercury that will provide key new observations for understanding Mercury's formation and evolution, and will be critical for selecting the site for a future landed mission. The three main mission goals are 1) identifying and mapping the distribution of minerals on the surface, 2) high-resolution imaging (1 meter per pixel) and 3) imaging of ice deposits in permanently shadowed regions (PSRs).

A novel component of the mission is the use of a solar sail as the primary propulsion method. The solar sail has scientific, technical and budgetary advantages. These include that it: 1) lowers the total cost of the mission, 2) lowers transit time, 3) allows long orbital phase durations (>10 years) and 4) can be used as an illumination source for imaging the permanently shadowed regions (PSRs).

Solar Sail: The sail is ~2500 m² in area, similar in size to that used for the Solar Cruiser mission. The sail is made from 2.5 micron thick, aged and aluminized CP1. This is similar to the material used in the heat shield of the James Webb Telescope. The sail consists of four separate quadrants, each rolled into a small drum, along with their carbon fiber supports (Figure 1).

For a nominal total payload mass of 365 kg, transit time to Mercury could be 5.3 years with no ΔV from launch. With a dedicated launch, transit time could be as short as 3.8 years. It would take ~50 days to transfer into a polar orbit, and then 176 days to map the entire surface. A highly elliptical orbit similar to MESSENGER's could be used, but due to the unlimited

'fuel' of the sail, the perigee point could be evolved during the mission from the north pole to the south pole, providing high resolution coverage of the entire planet, while retaining the thermal management benefits of the elliptical orbit. The orbit is maintained by changing the angle of the sail with respect to the Sun, and so the instruments must be gambled for pointing control.

The duration of the mission is limited not by fuel, but by the degradation of the sail. Preliminary analysis indicates it will last at least for 10 years, which could be increased with additional coatings such as Cr.

InterMediate InfRared (IMIR) Spectroscopy: Mercury poses significant challenges for mineral identification by remote sensing. Both the low Fe contents of silicate minerals and high degree of space weathering conspire to mute VNIR absorptions that have been used to great advantage on many other planetary bodies. The 4-8 micron spectral range (IMIR) has been shown to contain diagnostic bands for olivine, orthopyroxene, clinopyroxene and plagioclase feldspar (Fig. 2; [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. The strength of the bands also appears to be robust with respect to space weathering. More recent studies have shown distinct bands for SiO₂ polymorphs (Kremer et al abstract in this meeting) as well as for CaS [2]. In sum, an IMIR spectrometer would be uniquely well suited for identifying and mapping the distribution of major phases (silicates and sulfides) on Mercury's surface.

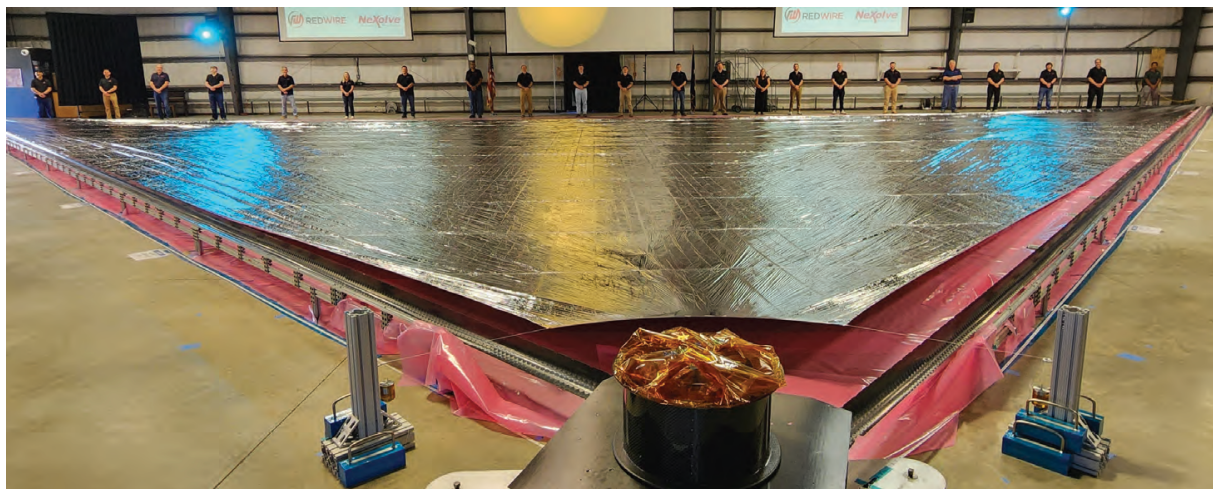


Figure 1. One quadrant of the Solar Cruiser sail, successfully unfurled during TRL5 testing in 2022. Note people for scale along the top of the image. Unspooled sail drum at bottom center of image.

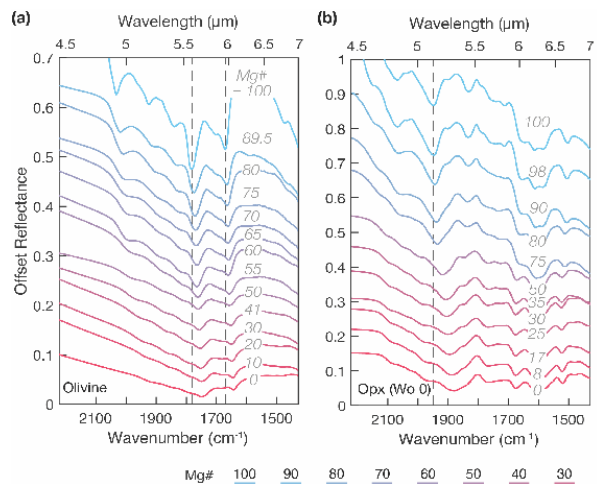


Figure 2. *IMIR spectra of olivine (left) and orthopyroxene (right), as a function of composition. Note a distinct shift in wavelength and increase in band depth with higher Mg content [1].*

An IMIR spectrometer is being developed at JPL. It is based on an optically fast compact Dyson imaging spectrometer scaled from EMIT on the ISS, and uses a unique HOT BIRD detector developed at JPL. To complement the IMIR spectroscopy measurements, a small radiometer instrument would be included to measure surface temperature.

High Resolution Imaging: Imaging at the 1 meter per pixel scale would benefit nearly all aspects of the study of Mercury's surface. High value targets for high resolution imaging include craters, lava flows, hollows, faults and pyroclastic deposits. The long mission duration afforded by the solar sail would allow repeated imaging of features over 10 years or more. This would allow monitoring of changes due to currently active processes such as hollow formation [3], fault movement [4], space weathering and crater degradation. The footprint of the high-resolution images is necessarily small. Here again, the long duration allowed by the solar sail will greatly increase the amount of Mercury's surface that can be imaged at high resolutions, compared to a chemical propulsion system. Finally, for future landed missions on Mercury, both costs and risks can be minimized with the 1 meter per pixel images, allowing selection of smooth landing sites, with reduced requirements for terrain hazard avoidance systems.

The camera envisioned is similar to the DRACO instrument flown on the DART mission. This had a pixel size of 6.5 microns and a focal length of 263 cm. This should provide ~0.25 m GSD (ground sampling distance) at a 100 km orbital distance, and 1 m GSD at 400 km.

Imaging of Polar Ice Deposits: One of the most stunning discoveries of MESSENGER was the relatively large amount of ices found in permanently shadowed regions (PSRs) at the northern pole. High contrast stretching allows the deposits to be seen in some images from MESSENGER, but the image quality is limited [5]. High-resolution images of the PSR interiors would allow better estimation of their volume, distribution and temporal/thermal evolution. Here, the solar sail provides a unique scientific advantage, as it can be used as a giant mirror to illuminate the PSRs. Combined with the high-resolution camera, this should greatly increase the quality of imaging of the polar ice deposits immensely. As with the other regions of the surface, the long duration of the mission would allow monitoring of changes that occur in the deposits, including variations in the dark covering materials that are thought to be carbonaceous.

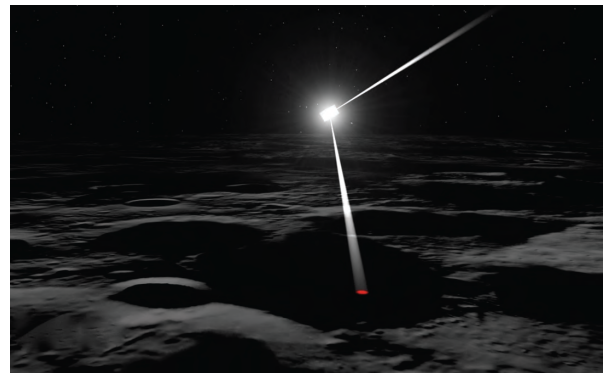


Figure 3. *Artist conception of using solar sail to illuminate ice deposits in PSRs. Marshall Space Flight Center.*

Site selection for landed missions: The next major phase of exploring Mercury will center on landed missions. The data provided by Mercury Scout will allow better selection of sites. The mineralogic maps and high resolution imaging will provide allow sites to be maximized for scientific return, while the high resolution images will allow risks to be quantified and minimized. 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] Carli et al. (2024) Minerals 14, 26. [3] Speyerer et al. (2022) GRL 49(16) e2022GL100783. [4] Watters et al. (2016) Nat Geoscience 9: 743-747. [5] Chabot et al. (2016) GRL 43: 9461-9468.