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Bridging from MESSENGER to BepiColombo – surface composition from visual and near-infrared observations and simulation of thermal infrared data

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Abstract

Retrieving information about the surface composition of Mercury from visual or infrared remote sensing data is a challenging task. Apart from observational difficulties, the high temperatures on the surface of Mercury affect the spectral characteristics of the constituent minerals. In order to address the latter issue we have used measurements of spectra of thermally cycled minerals taken at DLR's Planetary Emissivity Laboratory to analyze spectral reflectance data obtained during the first two Mercury flybys of Mercury by the MESSENGER spacecraft. Here we use the retrieved compositions to simulate spectra at mid-infrared wavelengths for comparison with future observations by the ESA BepiColombo mission and with ground-based observations.

1. Introduction

The MErcury Surface, Space ENvironment, GEo-chemistry, and Ranging (MESSENGER) spacecraft is the first to orbit Mercury. It is providing us with a rich dataset that is fundamentally changing our views of the innermost planet. Analysing the data is challenging in many ways and requires new approaches. Two of these novel approaches enabled the work presented here. First was the establishment of the Planetary Emissivity Laboratory (PEL) at DLR to obtain spectral measurements at temperatures appropriate to Mercury. Although still in its final verification phase, the PEL has already produced a number of interesting measurements indicating that thermal cycling can markedly change the spectral characteristics of minerals. In addition, a novel analysis method incorporating principal component analysis (PCA) and a clustering approach was applied successfully to observations from MESSENGER's Mercury Atmospheric and Surface Composition Spectrometer (MASCS), even in the absence of a photometric correction.

The analysis of the MASCS data presented here is another step toward understanding the surface composition of Mercury. Data to come from the MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS) on BepiColombo will build on the analysis by MASCS and provide complementary spectral information at thermal infrared wavelengths. It is therefore instructive to predict what MERTIS might observe given the MASCS observations.

2. The instruments

2.1. MASCS

The MASCS instrument [1,2] consists of a small Cassegrain telescope with an aperture that simultaneously feeds an Ultraviolet and Visible Spectrometer (UVVS) and a Visible and Infrared Spectrograph (VIRS). VIRS is a fixed concave-grating spectrograph with a beam splitter that disperses the spectrum onto a 512-element silicon visible photodiode array and a 256-element indium-gallium-arsenide infrared photodiode array with a spectral resolution of 5 nm. VIRS has a circular field of view with a circular diameter of 0.023°. The visible (VIS) detector of VIRS covers the wavelength range from 300 to 1050 nm, and the near-infrared (NIR) detector covers the range 850-1450 nm. The study of Mercury's surface presented here made use only of the VIRS channel of MASCS.

2.2. MERTIS

MERTIS [3,4] is an instrument on the Mercury Planetary Orbiter spacecraft of ESA's BepiColombo mission, which is scheduled to arrive at Mercury in 2020. MERTIS is designed to infer rock-forming minerals, to map surface composition, and to study surface temperature variations on Mercury with an uncooled microbolometer detector. MERTIS combines a push-broom grating thermal infrared spectrometer (TIS) with a thermal infrared radiometer (TIR) that share the same optics, instrument electronics, and in-fight calibration components and span wavelength ranges of 7-14 and 7-40 µm, respectively.

3. Spectral analysis

Newly available visible and near-infrared biconical reflectance spectra from the PEL are used to decipher the composition of Mercury's surface from MASCS observations. To avoid photometric correction, we analyze only a small portion of the surface, thus limiting the ranges of emission and phase angles in MASCS data. We acquired spectra of characteristic mineral samples, fixing the emission and incidence angle on the target material to 45º. This design gave us a set of observations directly comparable to surface regions observed at similar geometry, between 230° and 250°E during MESSENGER's first flyby (M1) and 20° to 40°E during the second (M2) [5]. The laboratory samples constitute a subset of the candidate Mercury minerals selected in preparation for BepiColombo MERTIS data analysis [6]. The subset includes calcium-rich plagioclase feldspar, magnesium-rich olivine and pyroxene, a representative glassy phase, and a titanium-rich oxide. For the samples analyzed we used the smaller grain size (0-25 µm) of typical PEL samples. All materials were heated to 500°C after measurement of reflectance and were then remeasured. The purpose of such heating was to simulate the thermal cycles that operate on Mercury surface material every solar day, and were motivated by our previous work indicating that thermal cycling can induce structural changes in common rock-forming minerals, such as plagioclase [7]. We analyzed the two MASCS datasets by combining a local PCA to retrieve the number of varying end-members and an iterative linear unmixing algorithm, based on least squares minimization and iterative elimination of negative concentrations. For each run, the analysis yields a vector of areal fractional concentration (the mass fraction divided by density and by particle size) for each input end-member.

5. Surface composition retrieved from MASCS data

The small sample set used for this analysis, remaining issues with the MASCS dataset, and the possibility that solutions are non-unique preclude derivation of a definitive mineralogy for Mercury. However, using the two sets of samples, one consisting only of fresh samples, the other containing both fresh and heated samples, provided instructive insights. The analysis with only fresh samples (a standard approach with spectral libraries) yields an abundance of almost 23% FeO and 18% TiO_2. Including the heated samples, which may be more representative of conditions on the surface of Mercury, reduces the FeO content to 13% and the TiO_2 content nearly to zero. The latter figures are consistent with recent results from MESSENGER's X-Ray Spectrometer [8,9] and show consistency with previous ground-based observations [10].

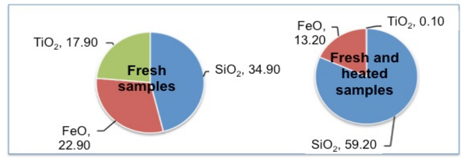

Figure 1. Relative abundances [in % area] of major constituents retrieved from the linear unmixing of MASCS spectra in terms of laboratory spectra (left: fresh samples only, right: including heated as well as fresh samples).

6. Outlook

At PEL the mid-infrared spectra of laboratory samples can be measured at temperatures up to 500°C, i.e., peak dayside temperatures on Mercury. These measurements are being used to simulate, by linear mixing, spectra in the wavelength range 7-14 µm for comparison with future measurements by MERTIS and with ground-based mid-infrared measurements. Analysis of visible and near-infrared observations at Mercury has been limited to date to data from the first two MESSENGER flybys, but extension to orbital observations is underway. The approach presented here has the potential to provide important constraints on our understanding of the global surface composition of Mercury.

References

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