SPECTRAL SIGNATURES OF GLASS ON LUNAR ANALOGUE ROCKS.

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Introduction: The BepiColombo mission is a joint project of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA). It started its seven year journey to planet Mercury on 20th October 2018. On 10th April 2020, the spacecraft swung by the Earth and the MErcury Radiometer and Thermal Infrared Spectrometer (MERTIS) [1] acquired the first high-resolution space-based thermal infrared measurements of the lunar surface. To extract emissivity spectra (7-14 µm) of the Moon, we carefully calibrated the radiance data of the spectrometer using an advanced fractal thermal roughness model [2].

Based on laboratory measurements of Apollo samples [3] and rare telescopic measurements [4] in the thermal infrared, the emissivity spectra of the Moon were expected to exhibit a strong Christiansen feature around 8 µm. However, the emissivity spectra of the flyby are different. They have an emissivity minimum near 8 µm and a maximum around 9 µm that did not yield a clear identification of the mineral phases that are known to occur on the Moon [5]. There is no clear silicate mineral composition or other effects such as grain size, temperature, or submicroscopic iron that can easily account for the spectral shape. Further, no significant spatial variations are found across the lunar disk. To explain the shape of MERTIS lunar flyby spectra, [6] outlined a working hypothesis: The uppermost layer of the regolith underwent extensive space weathering and is dominated by some glassy component such as a glassy layer, a higher abundance of agglutinates or glassy mineral rims. This layer, known as the epi-regolith, could not be preserved by any sample return mission so far. Further, strong thermal gradients are known to form in the uppermost layer of the lunar regolith which are responsible for spectral shifts [7,8,3]. To test this hypothesis, radiative transfer simulation with DISORT [9] were carried out [2]. It was found that a glassy layer on top of the regolith together with strong thermal gradients can qualitatively explain the absence of the 8 µm feature and the presence of the maximum at 9 µm.

MERTIS on BepiColombo: MERTIS on BepiColombo Mercury Planetary Orbiter (MPO) consists of a push-broom IR-spectrometer (-TIS) and a radiometer (-TIR) [1]. MERTIS-TIS and -TIR make use of the same optics, electronics, and in-flight calibration components [10-12]. MERTIS-TIS operates at wavelengths of 7-14 µm, has 78 spectral channels, and a spectral resolution of $\lambda/\Delta\lambda$=78-156. The radiometer operates between 7 and 40 µm with 2 spectral channels. Depending on surface characteristics, MERTIS spectral resolution is adapted to optimize the S/R ratio to resolve weak spectral bands with < 1% contrast.

During the Earth/Moon flyby on April 10th 2020, due to the flight configuration, only some instruments on BepiColombo were able to operate. Among them, the MERTIS imaging spectrometer provided the first hyper-spectral observations of the Moon in the thermal infrared (TIR) wavelength range from space.

Set-up description: At the Planetary Spectroscopy Laboratory (PSL), a spectral library for lunar analog samples in the TIR spectral range, measured under simulated Moon surface conditions, has been built to help the interpretation of MERTIS' Moon spectra. Three identical FTIR instruments evacuated to ~0.1 mbar are operating at PSL in an air-conditioned room.

Spectral measurements: External simulation chambers are attached to the FTIR spectrometer to measure the emissivity of solid samples. A high efficiency induction system heats the samples under vacuum to temperatures from 320 K up to above 900 K, while keeping the chamber at almost ambient temperature. Sample cups are made of stainless steel and have elevated rims enclosing the samples heating it from all sides. A large number of temperature sensors in the emissivity chamber are allocated to measure the sample temperature as well as monitoring the range of equipment and chamber temperatures. The same spectrometer allows measuring the bi-directional reflectance of samples, with variable incidence and emission angles between 0° and 85°. Integrating spheres (with gold or PTFE mirrors) allow for hemispherical reflectance measurements. Reflectance is measured under vacuum conditions in the 0.2 to >200 µm spectral range.

Sample selection, preparation and measurements: The most prominent rocks on the lunar surface are basalt, anorthosite, and breccia. The mare regions are rich in basalt, and it is believed that those basalts originated some 100 km below the surface, and were then brought to surface by meteoritic impact via the cracks created by the impacts. The highlands are regions not covered with basalts and are dominated by anorthosite and basin ejecta. Lunar breccias are fragmental rocks consisting glass, and minerals embodied into a matrix. Lunar soil is mainly composed of basalt, anorthosite and breccia. The fragmental structure of the lunar soil is the result of permanent bombardment of the surface by meteoroids [Lunar Sourcebook].

For our experiments and successive spectral measurements, we chose 2 simple lunar soil simulants, basalt and anorthosite, and 3 glass simulants: synthetic glass, basalt glass and obsidian, all natural samples except the synthetic glass. Samples were measured in emissivity at 140°C surface temperature and at room temperature in hemispherical reflectance. We measured pure soils and glasses, and for each soil a sample with 20 µm glass deposited on top. After being measured in emissivity, the samples were heated in the oven at 900°C for 4 hours and then again measured in emissivity at 140°C.

Results and Discussion: The figure below shows emissivity spectra of the pure mineral or glass powder (black, green), the mineral powder with a glassy layer on top (light blue), and the mineral powder with a glassy layer that was heated to 900°C (blue). Six configurations with anorthite and basalt as a base and synthetic glass, basalt glass and obsidian on top were considered. For any glassy layer on top of anorthite, no strong shifts of spectral bands are apparent but the spectral contrast becomes a little smaller. It is remarkable to see that the emissivity maximum of the heated basalt glass and obsidian on top of basalt yield a significant shift toward 9 µm. This is the first experimental reproduction of a strong spectral shift due to a thin glassy layer. It may support the hypothesis formulated in [6] that explains the spectra of the MERTIS lunar flyby, and further analysis is currently ongoing.

References:

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