Japan Geoscience Union Meeting 2012
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PPS01-01 会場:101B 時間:5 月 22 日 15:30-15:45

月、水星、大気の無い岩石天体の宇宙風化作用
Space weathering on the Moon, Mercury and airless silicate bodies

佐々木 晶[1*], 廣井 孝弘[2], 横田 康弘[3]
SASAKI, Sho[1*], Takahiro Hiroi[2], YOKOTA, Yasuhiro[3]

[1] 国立天文台, [2] ブラウン大学, [3] 国立環境研究所
[1]National Astronomical Observatory of Japan, [2]Brown University, [3]National Institute for Environmental Studies

Space weathering is the process to change surface optical property of airless silicate bodies such as the Moon, Mercury and asteroids. Typical changes are darkening, spectral reddening, and attenuation of absorption bands in reflectance spectra. The space weathering is caused by the formation of nanophase metallic iron particles in amorphous surface coatings of regolith grains, which was formed by high velocity dust impacts as well as irradiation of the solar wind ions. Those nanophase iron particles were discovered in lunar soils, Kapoeta meteorite, and recently in dust grains of asteroid Itokawa brought by Hayabusa spacecraft. Experimental studies using nano-second pulse laser showed the formation of nanophase ion particles on the surface of iron-bearing silicate should control the spectral darkening and reddening.

Mariner 10 and MESSENGER showed that Mercury is dark in albedo but has more impact craters associated with bright rays than the Moon. Space weathering rate on Mercury's surface might be slower than that of the lunar surface, although dust flux and solar wind flux causing the weathering should be one order of magnitude of greater on Mercury than on the Moon. This could be explained by compositional difference. MESSENGER showed low surface Fe abundance (less than 4 wt%). On the Moon, weathering degree of mare region is usually higher than that of the highland. This would be also ascribed to the difference of Fe abundance.

Increase in the size of nanophase iron particles should affect space weathering. The size might increase under high temperature of several 100 C, which could suggest latitude dependency of the space weathering degree: less optical change at lower latitude. Simulation experiments of laser irradiation showed apparent growth of nanophase iron particles after repetitive irradiation. The repetitive heating by high velocity dust impacts will cause the saturation of space weathering on Mercury.

From KAGUYA SP data of the Moon, estimated global reflectance map after solar phase angle correction shows that the both high latitude (over 75deg) regions have anomalously low color ratio (1547.7 nm/752.8 nm), which suggests lower degree (immature) space weathering. This could be caused by small cross section for solar wind proton supply. On Mercury, observed asymmetry of magnetic field might change the influx of solar wind particles, which would cause different current space weathering rate, although most of dark area of Mercury would be mature in weathering.

Dust grains of Itokawa contain not only nanophase iron but also nanophase FeS particles on the surface deposited amorphous layer. Probably nanophase FeS might also contribute the space weathering. MESSENGER discovered the surface concentration of sulfur. Probably FeS nanoparticles may exist and contribute in space weathering on the surface of Mercury.

キーワード: 月, 水星, イトカワ, 反射スペクトル, 宇宙風化作用, 年代
Keywords: Moon, Mercury, Itokawa, reflectance spectrum, space weathering, age

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Laboratory Measurements of Spectral Reflectance of Possible Mercury-analog Materials
Laboratory Measurements of Spectral Reflectance of Possible Mercury-analog Materials

Noam Izenberg[1]*, Charles A. Hibbitts[1], Rachel L. Klima[1], Andrew S. Greenspon[1], Ann L. Sprague[2], Deborah L. Domingue[3], Jorn Helbert[4]
IZENBERG, Noam[1]*, Charles A. Hibbitts[1], Rachel L. Klima[1], Andrew S. Greenspon[1], Ann L. Sprague[2], Deborah L. Domingue[3], HELBERT, Jorn[4]

[1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, [3]Planetary Science Institute, Tucson, AZ 85719, USA, [4]DLR, Rutherfordstrasse 2, Berlin, Germany
[1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, [3]Planetary Science Institute, Tucson, AZ 85719, USA, [4]DLR, Rutherfordstrasse 2, Berlin, Germany

The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) [2] on the MESSENGER spacecraft [1] has been observing Mercury from orbit since 29 March 2011 and has obtained more than 1.4 million near-ultraviolet to near-infrared spectra of the Mercury surface during the first ten months of operations. The Visible and Infrared Spectrograph (VIRS) channel on MASCS covers the wavelength range 300-1450 nm. VIRS reflectance spectra have shown no unequivocal evidence of the absorption band centered near 1000 nm wavelength associated with the presence of ferrous iron in silicates. The lack of this absorption and evidence of ultraviolet (UV) absorption shortward of 300 nm is consistent with the possibility of very low iron content (2-4 wt% FeO) [3].

Two key factors that may affect the relative shape (breadth, depth, and band center), and thus the detectability, of subtle bands in reflectance spectra measured by MESSENGER are (1) the viewing geometry of the MASCS observations, (MESSENGER orbital and pointing constraints restrict reflectance observations of Mercury to a phase angle range between 78 and 100 deg., with average incidence and emission angles between 39 and 50 deg.); and (2) the high temperature of the dayside Mercury surface, which can exceed 400 C [4].

Photometric variations affect reflectance properties [e.g., 5,6], which is one reason most laboratory-standard observations are conducted at incidence-emission-phase angles of 30-0-30 deg. Few laboratory observations of relevant materials cover the viewing geometry range to which Mercury observations are restricted. Similarly, high temperatures affect the reflectance properties of soils [e.g., 7,8,9], but few measurements have been conducted at Mercury surface conditions, or of materials likely to be important on Mercury.

We are conducting a pair of related studies at the Brown University Reflectance Laboratory (RELAB) and the optics laboratory of the Applied Physics Laboratory (APL) to understand the effects of photometry and temperature on reflectance spectral properties. At RELAB, we are examining materials (starting with low-iron pyroxenes and komatiites) at a MESSNGER-like range of incidence, emission, and phase angles, from ~350 nm to over 2000 nm with the purpose of providing proper photometric comparisons of known laboratory samples to Mercury observations.

Variation of reflectance with temperature for a given mineral can be wavelength dependent and non-uniform. At APL, we are investigating thermal effects on spectral reflectance of rock-forming minerals from UV through near-infrared wavelengths under vacuum and over a temperature range of -100 to 400 C. Several studies [e.g., 8,9] show that silicate absorption bands tend to widen, shoal, and shift position with increasing temperature. In the near-infrared, the ~1000 nm Fe2+ crystal-field absorption bands shift shortward for olivines, and longward for orthopyroxenes. The distorted M2 site 2000 nm absorption bands of orthopyroxenes also shift, though more subtly [7]. In addition, spectral slopes from UV through near-infrared can change, potentially affecting Fe and Ti compositions on Mercury, the Moon, and other solar system materials [10].

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キーワード: Mercury, Reflectance, Spectroscopy, Laboratory Studies, Infrared, Photometry
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The Planetary Emissivity Laboratory - high temperature spectroscopy of planetary analogs

The Planetary Emissivity Laboratory - high temperature spectroscopy of planetary analogs

Jorn Helbert[1*], Alessandro Maturilli[1], Mario D'Amore[1], Gabriele Arnold[1]
HELBERT, Jorn[1*], Alessandro Maturilli[1], Mario D'Amore[1], Gabriele Arnold[1]

[1]Institute for Planetary Research, DLR, Berlin, Germany
[1]Institute for Planetary Research, DLR, Berlin, Germany

The Planetary Emissivity Laboratory (PEL) at DLR in Berlin has a long-standing expertise in providing spectral data of planetary analog materials. Based on this experience we decided 5 years ago to extend our laboratory capabilities to support specifically missions to Venus and Mercury. Both planets exhibit surface temperatures up to 500C and this extreme temperature range affects the spectral characteristics of the surface minerals. First test data obtained in support of the NASA MESSENGER mission to Mercury highlighted the need for high temperature measurements. While the focus is on high temperature measurements the setup can be used to study also analogs for asteroids or the Moon. The measurements obtain so far helped the meaningful interpretation of the remote sensing data not only from MESSENGER but also from VenusExpress, and Spitzer observations. PEL is supporting the development of the JAXA mission Hayabusa 2 as well as the NASA mission Osiris-REX. The laboratory will play a key role in supporting the ESA-JAXA BepiColombo mission to Mercury.

The core instrument is a Bruker Vertex 80V, coupled to an evacuable high temperatures emissivity. This fourier-transform spectrometer has a very high spectral resolution (better than 0.2 cm^{-1}), and can be operated under vacuum conditions to remove atmospheric features from the spectra. To cover the entire from 1 to 100 micron spectral range, two detectors, a liquid nitrogen cooled MTC (1-16 micron) and a room temperature DTGS (15-300 micron) and two beamsplitter, a KBr and a Mylar Multilayer, are used. The spectrometer is coupled to a custom build planetary simulation chamber, which can be evacuated so that the full optical path from the sample to the detector is free of any influence by atmospheric gases. The chamber has an automatic sample transport system allowing maintaining the vacuum while changing the samples. PEL uses an innovative approach for heating the samples to temperatures of 500C. The samples are placed in a stainless steel sample cup, which is heated by a 1.5kW induction system. The induction heating system installed in the new chamber allows heating the samples to temperatures of 700K and more permitting measurements under realistic conditions for the surface of Mercury. The chamber can also be used independently as a vacuum-oven, to thermally process minerals and minerals which are afterwards measured in reflectance. Reflectance measurements are obtained with the Bruker A513 accessory. It allows bi-directional reflectance of minerals, with variable incoming and outgoing angles (between 13^o and 85^o). Samples are measured at room temperature, under purged air or under vacuum conditions, covering the 1 to 100 micron spectral range.

The second instrument currently available in the laboratory is a Bruker IFS 88 with an attached emissivity chamber, both purged with dry air to remove particulates, water vapor and CO_2. The chamber, which has been developed at DLR, consists of a double-walled water-cooled box with an attached blackbody unit. A heater in the chamber is used to heat the cup with samples from the bottom, for temperature from 20 up to 180 C. The chamber temperature can be set and maintained constant at typical working temperatures of 10 to 20 C. If necessary it can be cooled down to below zero. In addition a Harrick Seagull^{TM} variable angle reflection accessory mounted in the Bruker IFS 88 allows us to measure bi-conical reflectance of minerals at room temperature, under purging conditions in the extended spectral range from 0.4 to 55 micron.

The third instrument newly available in the laboratory is a Bruker IFS66v spectrometer. It allows measurements of the biconical reflectance at variable emergence and incidence angles as well as transmittance measurements between 1 and 25 micron. The reflectance measurements are comparable to the IFS88 but the instrument can be evacuated and has a significantly higher signal-to-noise ratio.

キーワード: Spectroscopy, Mercury, Moon, asteroids, High temperature
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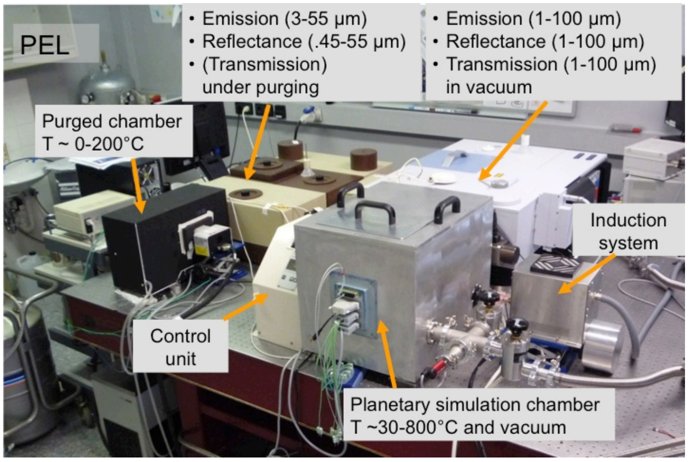

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Global classification of MESSENGER spectral reflectance data and lab spectra comparison.

Global classification of MESSENGER spectral reflectance data and lab spectra comparison.

Mario D'Amore[1*], Jorn Helbert[1], Alessandro Maturilli[1], James W. Head[2], Ann L. Sprague[3], Noam R. Izenberg[4], Gregory M. Holsclaw[5], William E. McClintock[5], Faith Vilas[6], Sean C. Solomon[7]
D'AMORE, Mario[1*], Jorn Helbert[1], Alessandro Maturilli[1], James W. Head[2], Ann L. Sprague[3], Noam R. Izenberg[4], Gregory M. Holsclaw[5], William E. McClintock[5], Faith Vilas[6], Sean C. Solomon[7]

[1]DLR, Rutherfordstrasse 2, Berlin, Germany., [2]Department of Geological Sciences, Brown University, Providence, RI 02912, USA., [3]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA., [4]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA., [5]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA., [6]Planetary Science Institute, Tucson, AZ 85719, USA., [7]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA.
[1]DLR, Rutherfordstrasse 2, Berlin, Germany., [2]Department of Geological Sciences, Brown University, Providence, RI 02912, USA., [3]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA., [4]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA., [5]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA., [6]Planetary Science Institute, Tucson, AZ 85719, USA., [7]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA.

The MESSENGER spacecraft continues to provide new data that change our views on the nature of Mercury's surface. Assuming that surface composition can be derived from spectral reflectance measurements with the use of statistical techniques, we have employed unsupervised hierarchical clustering analyses to identify spectral units from MESSENGER s Mercury Atmospheric and Surface Composition Spectrometer (MASCS) observations.

To retrieve the number and spectral shapes of the different components present in the dataset, we collected all MASCS observations to date (> 1.5 milion spectra). Because there are no photometric corrections for MASCS available yet, the data were normalized to the reflectance level at 700 nm, yielding a ratio nearly independent of incidence and emission angles. Independent tests on laboratory data show that this approach is effective in reducing phase angle variations. The data were then interpolated to a fixed spatial grid, averaging the sub-pixel spectra. The product is a map of reflectance ratio, along with error and frequency maps to address potential error in the process and to assess reliability. This is the first global geographically registered cube-image of averaged MASCS spectra. We produced a spatial grid resolution between 4 pixels per degree (ppd) for global analyses and 0.5 ppd for regional studies. The unsupervised hierarchical clustering of the global MASCS cube-image produces a tree of data partition, starting from two mega-regions (Fig 1). The first mega-region (MR1) comprises equatorial to mid-latitudes and the second (MR2) the two poles. The boundaries of MR2 at high northern latitudes approximate those of the volcanic northern plains [4]. MR2 areas show redder MASCS spectra than do MR1 areas. The spectral units show some correlation with surface units mapped by visible image acquired by MESSENGER and documented the presence of distinct spectral units on Mercury, as characterized by MASCS observations.Moreover, it seems to closely match some Gamma Ray Spectrometer elemental abudances results and global distribution of pyroclastic geological features. Following iteration produces finer separation of the surface in smaller regions. Each region average spectra is compared with reflectance spectra collected at the Berlin PEL laboratory. Here the angular dependency is treated as in the MASCS data, via normalization at 700nm. This allow us to start a geological and geochemical interpretations of MASCS observations [6,7]. The materials selected aim to explore the analogs for Hollow-Forming Material on Mercury theory in [5] : a komatiitic substrate with superimposed sulfides layer, due flotation in melted lava during volcanic eruption. We used komatiite spectra from PEL sample collection and various Mg-, Ca- and Mn- bearing sulfides [6,7]. both at low and high temperature to explore the thermal schok effect on sulfide volatilization and on komatiitic substrate.

Fig 1. Global MASCS cube-image rougher partition. The two mercurial mega-regions.

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キーワード: Mercury, Surface, spectra, VISNIR
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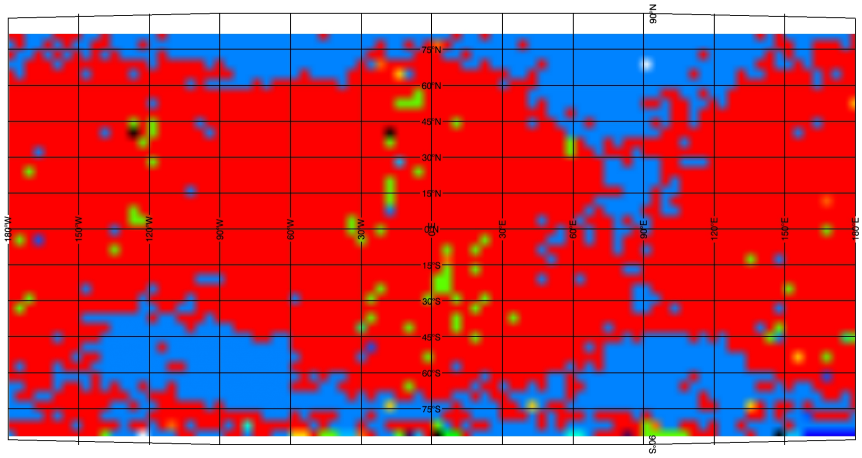

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多孔質表土ソイルへの衝突による月と水星の揮発性元素に富む内部形成
Impacts on porous regolith soils to form volatile-rich interior on the Moon and Mercury

三浦 保範 [1*]
MIURA, Yasunori[1*]

[1] 非常勤（大学）
[1]Visiting (Univs.)

本研究の結果は次のようにまとめられる。

1） 地球型惑星の表面は、広い結晶質基盤岩 (地球) と多孔質ガラス表土ソイル (月や水星) で覆われていると考えられる。

2） 不均質な月表面は、多重衝突で破壊された不均質な集合体である。それは、密度・空隙度・年代値から、月の古い高地の斜長岩が多重衝突により多孔質でガラス結晶混合していること、そして　FeO-Ni-Co-C 各含有量-年代値から初期の FA 斜長岩が動的な衝突形成をしていることから確認できる (Miura, 2012　印刷中)。

3) 月面の表土ソイルに炭素軽元素が富んでいる（地下の掘削試料からも確認）物質が形成されている。これは多孔質ソイル組織が内部に軽元素を運び、その結果跳ね返りの揮発性元素が減少して無大気月面（水星も基本的に同じ）を形成したことを示している (Miura, 2012　印刷中)。

4）表土ソイルの多孔質組織が鉄の富む深部と鉄に乏しいクラスト表面を水星の大きいコアを持つ内部からの重力で選別されたと考えられる。しかし衝突後でも月内部は鉄のコアの影響が比較的非常に弱いため鉄の多い月表面クラストが残されたとみられる。

5) 天体内部構造の主要な差（鉄含有量に相当）がほぼ同じサイズでも月（低密度）と水星 (高密度) の表面クラストの違いを結果的に生み出したと考えられる。

キーワード: 多孔質表土ソイル, 月と水星, 揮発性元素, 内部形成, 鉄コア, 内部保存
Keywords: porous regolith soils, Moon and Mercury, volatile elements, interior formation, iron core, interior reservoir