TEMPERATURE DEPENDENT SPECTRAL VARIATION ON THE SURFACE OF MERCURY.
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Introduction: Changing a mineral's temperature can affect how it reflects light, and such temperature-dependent spectral variations can be visualized via a mineral's thermospectrum [1-4]; the change in a mineral's reflectance with change in temperature (ΔR/ΔT), plotted as a function of wavelength. Planetary surface temperatures, in absence of direct *in-situ* measurements, cannot be characterized to the same accuracy achievable in laboratory trials, however thermospectral analysis of remotely sensed planetary datasets may provide constraints on surface composition if a given location can be observed at different temperatures while other (e.g. photometric) parameters are well understood. Generating thermospectra for a variety of rock forming minerals and planetary materials in-lab could provide vital context for interpreting thermospectral variation observed in planetary datasets.

Mercury's surface temperature can vary over several hundred degrees Kelvin during its day [5]. Spectra from Mercury's surface collected by the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) Visible and Infrared Spectrograph (VIRS) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft are generally smooth and red sloped (i.e. increasing reflectance with increasing wavelength), with almost no identifiable absorption features [4]. This has led to the hypothesis that Mercury's surface may be largely composed of glassy, space weathered, low iron silicates [4,5]. Studying the thermal behavior of Mercury's surface and analog materials could aid in the interpetation of these MASCS spectra by revealing absorbtion features masked by high surface temperatures.

We present a lab-generated thermospectrum for Mg olivine, utilizing methodology intended to produce a thermospectral library of planetary materials to aid interpretation of surface spectra of solar system bodies obtained from orbit. We also present a preliminary analysis of MASCS data used in conjunction with a thermal model [6], indicating that multiple sites on Mercury's surface show no thermospectral effects between 0.4-0.7μm, despite temperature variation of up to 542K. Additionally, spectral shape and temperature show no clear relationship between 0.91-1.44μm. However slight increases observed in average thermospectral magnitude and slope in near-infrared region relative to that in the visible region may indicate that MASCS reflectance data at long wavelengths is influenced by thermal emission.

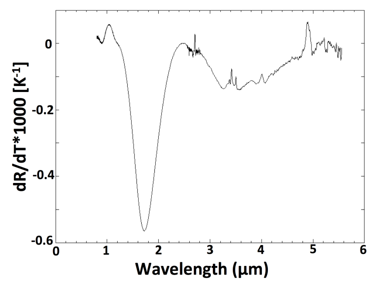

Figure 1. Laboratory generated thermospectrum for Mg olivine, calculated from corrected NIR reflectance spectra collected between a 333-550K temperature range.

Laboratory thermospectrum of Mg olivine: We mounted ~0.34 g of powdered Mg olivine in a copper sample holder, comprising a shallow sample well with an integrated thermocouple in direct contact with powdered sample, behind an MgF_2 glass window. Olivine was heated and cooled under high vacuum conditions (10^{-7}-10^{-9} torr) to prevent oxidation. Vis-NIR spectra covering a 0.45-5.2μm wavelength range were collected using a purged FTIR spectrometer standardized to a powdered magnesium fluoride white reference [3]. The sample was cooled to 150K and spectra collected at consistent time intervals as the sample re-warmed to 300k. The sample was then heated to 550-600K and spectra collected at regular time intervals as the sample cooled to 300K.

Thermospectrum calculation. Corrected reflectance vs. temperature was plotted for each sampled wavelength, and normalized to measured reflectance at 300K. (ΔR/ΔT) was then characterized for each wavelength using a linear least squares regression, and [(ΔR/ΔT)*1000] plotted as a function of wavelength to generate the final thermospectrum (Fig. 1).

Thermospectrum analysis. Temperature dependent spectral variation observed in Mg olivine during this study is consistent with variations previously reported for olivine [Fig. 1, 1,2]. The shape of our lab generated Mg olivine thermospectrum bears resemblance to the Mg olivine thermospecrtra reported by [2]. Both the magnitude and location of major thermospectral features differ significantly, likely due to differences in olivine sample composition.

Thermospectral Effects on Mercury: Two- or three-temperature thermospectra were generated for 16 locations with similar compositions on Mercury's surface, where spectral footprints from multiple MASCS ground tracks intersected. Calibrated reflectance spectra from intersecting footprints were pulled from the Planetary Data System (PDS), and model surface temperatures calculated for each spectra [6]**.** A thermospectrum was then generated for each location by characterizing ($\Delta R/\Delta T$) per wavelength using least squares linear regression and plotting [($\Delta R/\Delta T$)*1000] as a function of wavelength (Fig. 2). Spectral variation at these locations was also assesed using methodology utilized on the asteroid 433 Eros [2] (Fig. 2).

Mercury's shortwave thermospectra are flat and reveal no significant changes in surface reflectance with temperature, despite large temperature shifts (Fig. 3). The shape of reflectance spectra analyzed using methodology used for Eros [2], also show no systematic variation with temperature in both the 0.4-0.7 µm and 0.91-1.44 µm range (Fig. 2b, 3). Conversely, thermospectra of the asteroid Eros in the same wavelength range demonstrate clear, systematic variation in spectral shape [Fig. 2a, 2]. Location based thermospectra derived from intersecting ground tracks on Mercury suggest that thermospectral slope in the NIR region is generally positive (Fig 3). This could represent a longwave thermospectral effect. However, this trend could also suggest that thermal emission may influence spectral shape at increasing wavelengths [7]. Thermal emission has been modeled as increasing Mercury's reflectance in a non-linear fashion with increasing wavelength and temperature at wavelengths beyond ~1.5 µm [7]. Variation of this nature would be capable of producing a small uptick in thermospectral slope at increasing wavelengths.

Discussion: The lack of thermospectral variation observed on Mercury's surface may place constraints on the nature of materials present at our analyzed locations, implying that space weathering, fine grain size, glass, and nanophase iron may dominate the spectral features of the regolith [5,8]. The absence of temperature-dependent spectral variation on Mercury may suggest that its surface has been permanently altered to such a degree that expected heating effects are not possible. This supports the hypothesis that Mercury's surface materials have been extensively processed by thermal cycling [9] and further that the smooth, featureless nature of MASCS spectra may be strongly influenced by space weathering processes. Formal characterization of thermal behavior of known surface units on Mercury could constrain the nature and extent of space weathering processes altering/covering the planet's mineral signatures, and thus compositional interpretations derived from MASCS spectra. Additionally, further analysis to resolve spectral noise encountered in the IR region is required to investigate whether potential longwave thermal emission effects can be quantified, and if possible corrected in future releases of MASCS data.

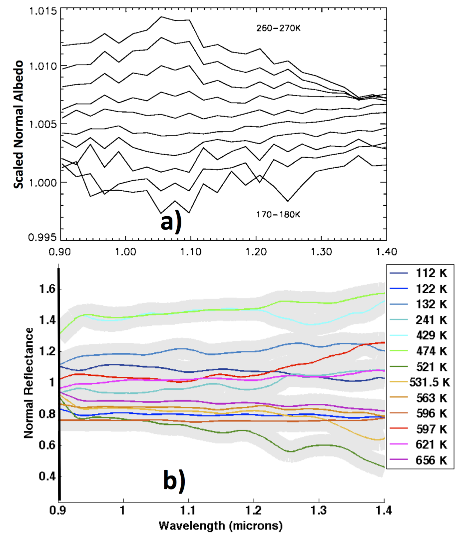

Figure 2. **a)** Figure edited from [2], showing systematic variation in spectral shape with varying temperature on 433 Eros [9]. Spectra are averaged over 10 K temperature intervals, normalized to the spectral average across all temperature bins, and offset by .0012 from neighboring spectra. **b)** Smoothed Reflectance spectra from 12 sites on Mercury's surface, averaged over 10 K temperature intervals and normalized to the spectral average across all temperature bins. Spectral shape and magnitude show no systematic variation with changing temperature. Uncertainty envelopes plotted for each spectrum in grey represent a 90% confidence interval using the highest standard deviation value recorded among averaged spectra.

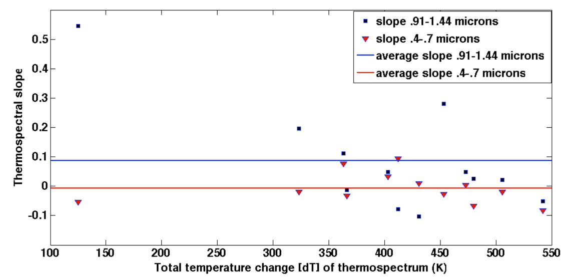

Figure 3. Thermospectral slope for each studied location vs. the temperature range of spectra at that location. The visible (0.4-0.7 micron) region shows a lower average thermospetcral slope (solid red line) than that of the near-IR (0.91-1.44 micron) region (solid blue line).

References: [1] Hinrichs, J. L., and Lucey, P. G. (2002). *Icarus*, *155*(1), 169-180. [2] Lucey, P. G. et al. (2002). *Icarus*, *155*(1), 181-188. [3] Izenberg, N. R. (2014) *EPSC2014*, *EPSC Abstracts,*Vol. 9, Abstract #776-1. [4] Izenberg, N. R. et al. (2014) *Icarus*, *228*, 364-374. [5] Domingue D. L. et al, (2014) *Space Sci. Rev. 181*, 121–214. [6] Paige, D. A. et al. (1992) *Science, 258*, 643-646. [7] Clark, R. N. (1979). *Icarus*, *40*(1), 94-103. [8] Riner, M. A., and Lucey, P. G. (2012) *J. Geophys. Res.* 39, L12201. [9] Maturilli, A., et al. (2014) *Earth Planet. Sci. Lett.* 398, 58-65.