**The Sub-Meter Surface Roughness of Martian Basaltic Lava Flows.** B. E. McKeeby, M. S. Ramsey Department of Geology and Environmental Science, University of Pittsburgh, 4107 O'Hara Street SRCC, Pittsburgh, PA, 15260 (bem101@pitt.edu)

**Introduction:** Characterizing the morphology of volcanic terrains from orbital remote sensing data is important for understanding a planet's eruption dynamics over time and vital if ground validation is not possible [1-4]. However, orbital instruments commonly have spatial scales in the tens to hundreds of meters per pixel, much greater than the degree of surface change observed between different lava flow morphologies and compositions. Surface roughness below the spatial resolution of thermal infrared (TIR) instrument data, however, does produce negatively sloped emissivity spectra at longer wavelengths either from an incorrect assumption of a uniform surface temperature and/or an incorrect choice of the maximum emissivity during temperature-emissivity separation of the radiance data [5,6]. Ground surfaces viewed at higher solar incident angles and/or emission angles will display greater amounts of sub-pixel anisothermality due to the increased areal percentage of shadows [7,8]. The resulting spectral slopes are distinct, with magnitudes proportional to the degree of surface roughness [5,6]. This study utilizes Thermal Emission Imaging System (THEMIS) TIR data acquired during Routine Off-Nadir Targeted Observations (ROTO) of the Mars Odyssey spacecraft to derive Root Mean Square (RMS) surface slopes at scales currently only achievable by ground-based methods.

RMS slope describes the distribution of maximum tilt (i.e., topographic gradient) at each point along a profile, separated by the step size or sensitivity of the measurement [5]. TIR data are sensitive to the degree at which surface units/roughness elements remain thermally isolated. This scale is estimated based on the surface's thermal inertia [5,6]. For the surfaces studied here, we estimate thermal isolation, and therefore RMS slope, on the 10 cm scale [5]. This is an order of magnitude higher than radar and high-resolution visible images, and four orders of magnitude more sensitive than rock abundance models derived from the THEMIS thermal inertia. As RMS slope is a function of scale, comparisons to other geological surfaces must also made at the same scale. At the 10 cm scale, terrestrial pahoehoe flows generally have average RMS slope values of 40°-50°, whereas a'a flows have average RMS slopes of 50°-60° [2].

A ROTO image set of Daedalia Planum, south of Arsia Mons and part of an extensive lava flow field, was chosen for this study [11,12]. High resolution images obtained by the High Resolution Imaging Science Experiment (HiRISE) instrument show diverse flow morphologies and prior multispectral analysis indicate unusual variations in thermophysical properties between individual flows. Previously, this region was identified as containing some of the roughest surfaces on Mars [6].

**Methodology:** The ROTO triplet used in this study was collected at solar incidence angles between 50°- 89° and emission angles between 1°- 28°. ROTO images were acquired in September 2017 centered at 237.62°E and -23.26°N. Standard THEMIS processing and atmospheric correction was performed on all images. The retrieved emissivity shows distinct spectral slopes that were modeled by combining the KRC thermal model with a Surface Slope Model to produce simulated radiance data at different RMS slope values. The spectral emission features of Martian dust were added to the model-produced blackbody radiance spectra prior to temperature-emissivity separation to represent the surface data more accurately. Measured surface emissivity is assumed to be a combination of surface dust plus atmospheric dust and water ice cloud.

**Results:** Near-isothermal surfaces can be adequately described with a single Plank radiance and display similar brightness temperatures (BT) at all wavelengths. Rough surfaces require higher temperatures to fit the plank curve at shorter wavelengths resulting in different BT across TIR wavelengths [13]. Temperature variations of up to 10K exists between nadir THEMIS bands 3 and 9 indicating surface anisothermality throughout the study region. The off-nadir views have a lower temperature difference of only 1-2K.

Several different classifications of flows are seen in this ROTO image set. Low albedo lava flows are seen as individual flows (Fig 1: Flow 1) and as levee material along large, channelized flows (Fig 1: Flows 2a & 3). In general, lower albedo flows show greater spectral slopes than the higher albedo flows suggesting increased temperature mixing and a potentially rougher surface. These flows were previously interpreted as a'a-like with eolian infilling of their central channels [12]. Low albedo lobate flows (Fig 1: Flow 1) display greater magnitude spectral slopes than the other surfaces studied. Higher albedo surfaces are also seen in lobate flow structures (Fig 1: Flow 4) and found in central channel material (Fig 1: Flow 2b). These dominate much of the ROTO scene. Higher albedo flows also exhibit negatively sloped emission spectra, but to a lesser degree compared to the low albedo surfaces.

**Discussion:** Surface roughness below the spatial resolution of TIR instruments produces negatively sloped emission spectra at longer wavelengths [5,6]. Greater magnitude spectral slopes indicate increased anisothermality. Overall, the nadir viewing geometry produced warmer BT and more negative spectral slopes than the off-nadir geometries [7,8]. This may be a function of spacecraft and solar azimuth, such that off-nadir viewing preferentially sees surfaces facing away from the sun and therefore appear more isothermal. Off-nadir viewing geometries exhibit BT differences of 1-2K between THEMIS bands 3-9 supporting this conclusion. Lower albedo flows are interpreted as rougher lava surfaces whereas higher albedo flows are considered to be more smooth. This is supported by prior work [11] and HiRISE data showing a greater amount of rough surface features in the low albedo flows compared to the high albedo ones.

**Conclusions:** ROTO data from the THEMIS instrument retrieves surface roughness down to the 10 cm scale. Evidence of this is demonstrated by the presence of negatively sloped TIR emission spectra. Different albedo flow surfaces display varying degrees of spectral slopes, indicating a range of surface roughness. The results reported here support those made by other authors [11,12] and the conclusion of subpixel checkerboard mixing of thermophysical units [12]. Additional work is needed to quantify the RMS slope magnitude and compare those to terrestrial values of a'a, pahoehoe, and other transitional textures.

**Future Work:** The off-nadir ROTO images exhibit near isothermal TIR spectra that are not optimal for surface roughness derivation, which requires sub-pixel temperature variation. Because of this, other daytime nadir images acquired at different seasons and times of day will be examined. Changes in solar illumination as a function of season and overpass time will provide data with different shadowing conditions rather than emission angle. These data, compared with the existing nadir ROTO image, will be modeled using the KRC thermal model and Surface Slope model to quantify the surface roughness through RMS slope [9,10].

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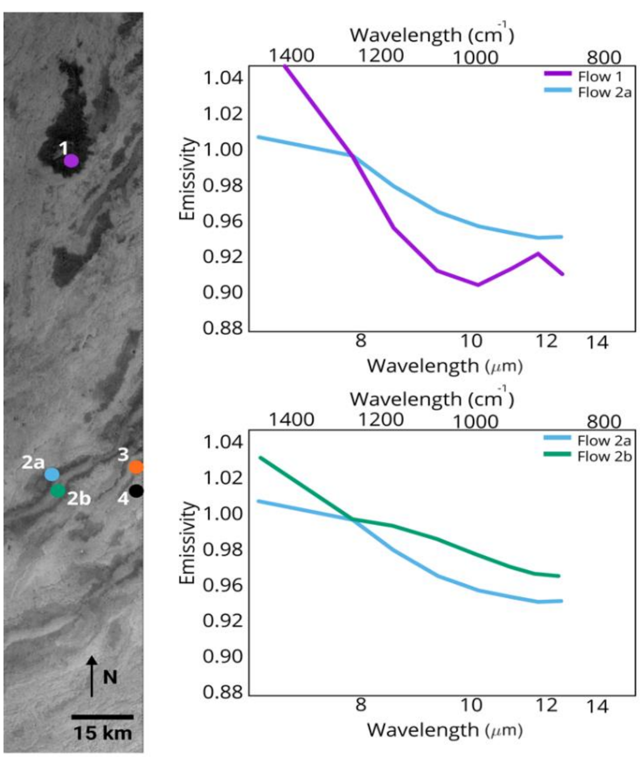


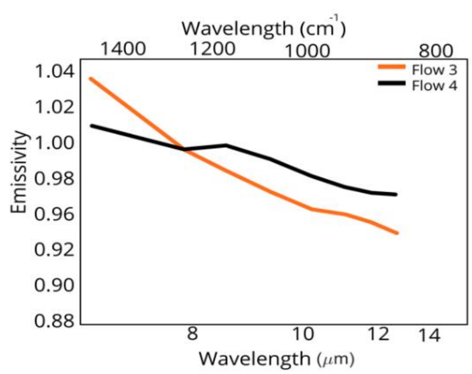


**Fig 1**. The flows studied are shown in the THEMIS image (left) and correspond to the same color spectra. All flows exhibit some degree of spectral sloping. In this region, TIR spectra are sensitive to features on the 10 cm scale. Low albedo flows (Flow 1) and levee material (Flows 2a & 3) show the greatest spectral slopes and are interpreted as rough surfaces, whereas higher albedo flows (Flows 2b & 4) are interpreted as smoother [11].