VALIDATION OF TANAGER, AN AUTOMATED HEMISPHERIC GONIOMETER. K. E. Lapo[1] and M. S. Rice[1], [1]Western Washington University, lapok@wwu.edu, and melissa.rice@wwu.edu, respectively

Introduction: The Western TANAGER (Three-Axis N-sAmple Goniometer for Evaluating Reflectance) is a new, open-source, automated, hemispheric goniometer, designed and built by First Mode, LLC for Western Washington University [1]. TANAGER was designed to study the visible to near infrared (VNIR) spectra of naturally weathered rock surfaces at a range of viewing geometries (incidence = -70º–70º; emission = -70º–70º; azimuth = 0º–170º). Detailed understanding of naturally weathered materials is key to interpreting complex data from Mars. Data collected by TANAGER will aid interpretations of VNIR spectra of weathered rock surfaces from orbital and ground-based spectrometers on Mars, including the Mastcam and Mastcam-Z (~400-1100 nm) multispectral instruments on the Curiosity and Perseverance Mars rovers.

TANAGER is unique in that it can accommodate multiple large, irregularly shaped natural samples, is fully automated, and the design and control software are available on GitHub, as outlined in [2]. Given the novel and open-source nature of this instrument, careful and thorough validation is vital to trusting and understanding all future data from the instrument and the design of the instrument as a whole. Evaluations of TANAGER's performance requirements are described in [1]. Here, we present initial validation results, with a focus on the Mastcam/Mastcam-Z wavelength range.

Methods: We performed experiments with TANAGER to characterize its influence on sample heating, internal self-consistency, and reproducibility of previously published results. We used witness samples of the Mastcam-Z calibration targets [3], which have been well-characterized by multiple spectrogoniometer facilities. These include cyan, green, red, yellow, black, gray33, and gray70 color standards manufactured by Avian Tech, and the AluWhite white reference manufactured by Lucideon.

We measured heating effects of the TANAGER light source on endmembers Lucideon black and white reference Spectralon® with an infrared laser thermometer with a verified ± 0.1° C accuracy. Endmember ambient temperature was measured before exposure to the light source and then measured every 2 minutes for an hour.

Duplicated TANAGER datasets were compared for internal consistency, and TANAGER datasets were compared to the results of Buz et al. (2019) [4] (hereafter "Buz et al.") for external validation. TANAGER interfaces with a Malvern PanAnalytical ASD FieldSpec4 Hi-Res reflectance spectrometer and we apply a Spectralon® white reference correction. We duplicated reflectance spectra and phase angle plots from Buz et al. for direct comparison of the two instruments' data sets. Relative root mean square error (RMSE) was calculated for each comparison of normalized spectra at a range of geometries.

Results:

Sample Heating Characterization. White reference Spectralon® yielded almost no increase in temperature over the hour of exposure, with an initial temp of 19.0° C and a maximum temperature of 19.4° C. Lucidean black increased in temperature by 6° C in the first 6 minutes followed by a slower increase to an apparent maximum of 28° C at 42 minutes. These are relatively minor temperature increases compared to those observed with other goniometer light sources [e.g., 2].

TANAGER Self-Consistency. Repeated TANAGER reflectance measurements for the grayscale targets at a range of incidence and emission angles yield a high level of visual fidelity (e.g., Fig. 1) with minor differences at the highest emission angles (e.g., e = 58º and 70°). Relative RMSE values comparing data collected with TANAGER for all samples and at a range of viewing geometries are 0.2 - 2.5%.

TANAGER Reproducibility of Published Results: TANAGER and Buz et al. data show a high level of consistency with some minor differences at high wavelengths (> 1900 nm) and at extreme geometries (e.g., e = 70°). Visual comparisons yield some differences, but RMSE of normalized data for Mastcam/Mastcam-Z-relevant wavelengths (400-1100 nm) confirm statistical consistency with accepted published data. Fig. 2 shows visual fidelity of red caltarget TANAGER data to Buz et al. data, except for e = 70° which is relatively more reflective in TANAGER than Buz et al. data. Similar patterns are seen in most caltargets. Fig. 3 shows normalized reflectance at various phase angles to demonstrate wavelength-dependent scattering patterns. TANAGER data shows lower normalized reflectance than Buz et al. data at high phase angles > 100° (Fig. 3) but scattering patterns are otherwise consistent.

Despite differences in the TANAGER and Buz et al. datasets, statistical analysis shows high fidelity at a wide range of phase angles. Relative RMSE values comparing data collected with TANAGER to that collected by Buz et al. are 0.5 – 2.7%, except for one backscattering black RMSE of 5.2%.

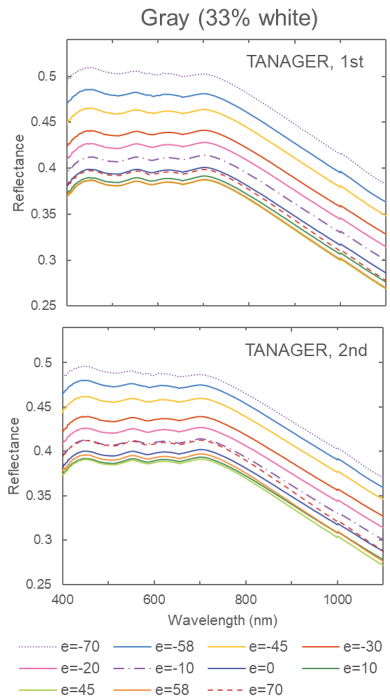

Figure 1: Duplication of Buz et al. (2019) figure 6 for the caltarget Gray33 with variable emission angles and i = 30° for 2 separate runs on TANAGER.

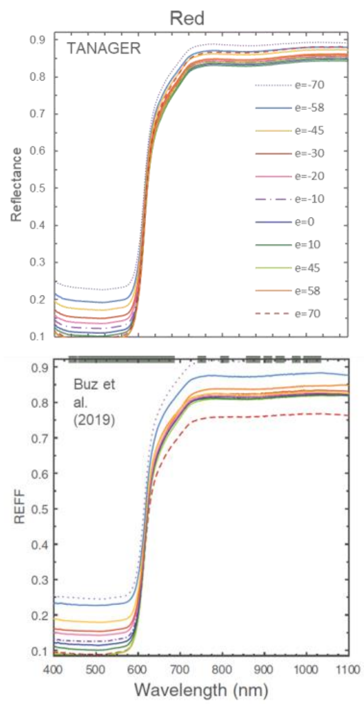

Figure 2: Duplication of Buz et al. (2019) figure 6 for the red caltarget with variable emission angles and i = 30° comparing TANAGER and Buz et al. (2019) data.

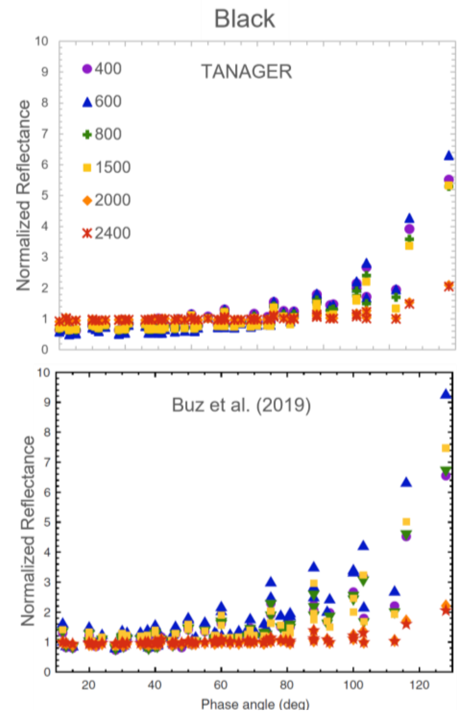

Figure 3: Comparison of Buz et al. figure 7 and TANAGER data for the black caltarget. All data is normalized to reflectance at g = 12°. Color coding represents wavelength values (nm).

Discussion: Initial heating experiments indicate a range of scenarios for different materials. Future work includes heating experiments on grayscale caltargets, slab and particulate natural materials, and paired spectra collection to test the effects on adsorbed water.

Visual comparisons and RMSE statistical comparison speak to the high level of repeatability of measurements collected with TANAGER. Further analysis should be completed for non-uniform materials to confirm repeatability for particulate and natural materials, which may see higher variability due to spot-location drifting or shifting of materials during sample tray rotation. While further work is warranted, this study provides an optimistic first order analysis.

Minor to moderate differences between Buz et al. and TANGER data can be observed in several spectra visualizations, but statistical differences are low: below 3% RMSE except for the low-signal black target at one geometry for Mastcam and Mastcam-Z relevant wavelengths. Relative reflectance differences like those seen in Fig. 2 for extreme emission angles are visibly perceptible, but RMSE values indicate statistical fidelity. Additional validation of high emission angle pointing and spot size may provide insight into the visible discrepancies seen in Fig. 2.

The differences seen in wavelength-dependent scattering in Fig. 3 are minor given the overall consistency in scattering patterns and low RMSE values. The small differences in magnitude at high phase angles may be explained by differences in light sources, different curvature of the fiber optic cable and may also benefit from additional validation of detector pointing and spot size. Low RMSE data overall confirm the accuracy of TANAGER data to Buz et al. data under the same conditions.

Future work includes verifying the pointing and spot size of the detector at high emission angles; continued validation of TANAGER through its entire 350-2500 nm wavelength range; continued validation on non-uniform natural, and particulate material; vibration analysis; and the influence of instrument heating on adsorbed water in target materials.

Acknowledgments: Funding was provided by the NASA Solar System Working program, Western Washington University, and the NASA Mars-2020 mission. We thank the Mastcam-Z team for use of the caltarget witness samples.

References: [1] Rice M.S. et al. (2022) *LPSC, this meeting*. [2] Hoza K. & Rice M. S. (2019) *LPSC, Abstract #2958.* [3] Hayes A.G. et al. (2021) *Space Sci. Rev., 217, 29.* [4] Buz J. et al. (2019) *Opt. Eng., 58.*