AN AUTOMATED GONIOMETER SYSTEM FOR REFLECTANCE SPECTROSCOPY.

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Introduction: Reflectance spectroscopy is a major technique for characterizing the composition of planetary surfaces, and has led to key findings such as the characterization of alteration minerals indicative of an aqueous, neutral-pH environment in Mars' past (e.g. [1,2]). When a reflectance spectrometer collects data, it does so at some viewing geometry, which is defined by the angular relationships between the light source illuminating the surface, the target material, and the detector (Figure 1). In the lab, this is usually at a standard viewing geometry (e.g. incidence=0, emission=30). In situ measurements taken by spacecraft, however, may be taken at a wide range of viewing geometries. This is known to have potential to influence spectral signatures, but work done to quantify the effects of viewing geometry on the spectra of natural rock surfaces has so far been limited.

Western Washington University's new automated goniometer enables the collection of reflectance spectra across a range of viewing geometries similar to those of spacecraft observations. By acquiring spectrogoniometric measurements for planetary analog samples in the lab, we will facilitate more comprehensive interpretations of spectral data from spacecraft than is currently possible.

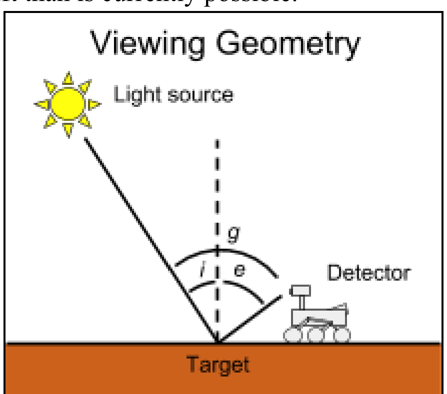

Figure 1: A 2-dimensional viewing geometry is defined by an emission angle *e* and incidence angle *i*. Phase angle *g* is the angle between *e* and *i*.

The Goniometer: In order to enable precise relative positioning of a light source, detector, and target material, a goniometer has been constructed to interface with WWU's reflectance spectrometer (Figure 2). It consists of an aluminum backboard with two rotating arms, one holding a light source and the other holding a detector. Azimuth angle is held fixed at 0 or 180 degrees, and incidence and emission angles can vary from 0 to 90 degrees with a minimum phase angle of 15 degrees based on geometric limitations. Stepper motors attached to the incidence and emission arms enable automatic iterations through geometries with 1 degree of angular resolution, which enables efficient collection of spectra at high angular resolution. When using the automation features, incidence angles are currently restricted to -50 to 50 degrees, and emission angles are currently restricted to -35 to 65 degrees because of mechanical limitations and geometric constraints. This geometric range was deemed sufficient to reproduce the vast majority of observations taken by orbital and ground-based reflectance spectroscopy instruments.

Samples may be positioned using either 1) a manually adjusted sliding tray for large samples or 2) an automated rotating tray for smaller samples. The manually-operated tray can accommodate samples up to 7 inches tall, and the automated tray can hold 5 samples 3 inches in diameter, plus a disc of Spectralon as a white reference material. This Spectralon white reference material has been shown to be an isotropic scatterer at the relevant viewing geometries [3]. This means that it is possible to collect a white reference at each viewing geometry, which corrects for the effects of changes in illumination spot size and detector field of view.

Figure 2: A goniometer enables precise positioning of a light source, detector, and target material.

The Light Source: This instrument incorporates a light source based on the design used by the HOSERLab at the University of Winnipeg [4]. It incorporates a USHIO FCS lightbulb and is powered by a BK Precision 1687B switching mode DC power supply. The bulb is rated at 150 W, but is run at 20 V and 114 W. This slightly decreased power output helps to reduce noise from heating the samples and detector.

The Detector: Signal is collected by a fiber optic cable with a 25 degree field of view, giving it a spot size with a diameter of 1.3 cm on the sample when emission is 0 degrees. This cable channels input signal to an Analytical Spectral Devices, Inc. (ASD) FieldSpec 4 Hi-Res spectrometer, which has three internal detectors collecting signal across 2151 channels. The detectors are a 512-element silicon array VNIR detector that measures from 350-1000 nm nm, and two graded index InGaAs photodiode Short Wave Infrared (SWIR) detectors that measure signal from 1001-1800 nm and 1801-2500 nm, respectively. Together, these detectors allow for sampling at a resolution of 3 nm from 350-700 nm and 8 nm at 701-2500 nm.

Control Software: Custom software designed to operate the system comes in two open source packages, one to control the spectrometer and the other to control the goniometer. Software for the spectrometer is available at https://github.com/kathleenhoza/autoasd and can also be installed using pip install autoasd. Software for the goniometer is available at https://github.com/kathleenhoza/autospec and can also be installed using pip install autospec.

Applications and Preliminary Results: This experimental setup allows for the rapid, automated collection of reflectance spectra for multiple rocks (powders, slabs or hand samples) at a large range of given geometries. For example, spectra for a suite of 5 samples at 10 different viewing geometries each can be acquired in under 1 hour, including time for processing and plotting data.

Research in this lab will focus primarily on applications to spectroscopic observations at Mars, including an ongoing study that aims to characterize Mars-relevant rock coatings and weathering rinds [5]. Because the spectra of coatings and rinds have been shown to vary with viewing geometry (e.g. [6]) measuring bi-directional reflectance for Mars-analog coated and weathered surfaces has the potential to improve our ability to characterize these coatings and their underlying substrate materials. To this end, the goniometer is currently being used to collect spectra for a suite of naturally-weathered, Mars-relevant surfaces, including weathered basalts from the Channeled Scablands of Eastern Washington State (Figure 3).

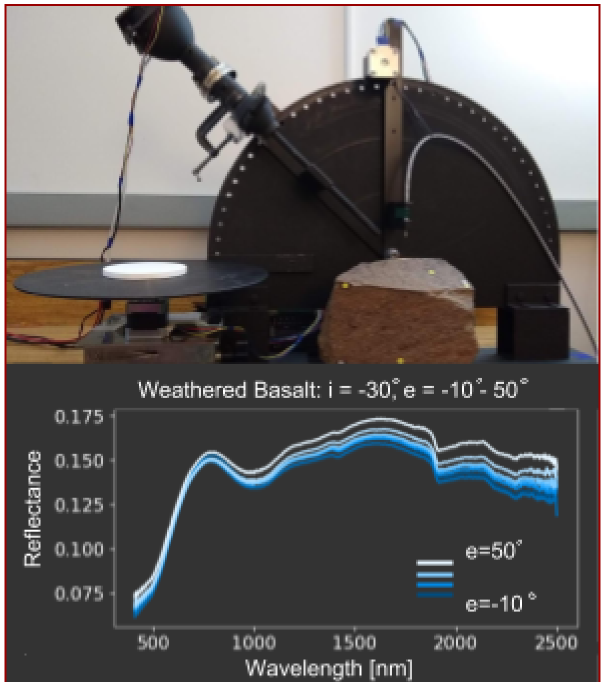

Figure 3A: When operated manually, the goniometer can accommodate cobble to small boulder sized samples. 3B: Spectra of a weathered basalt surface were acquired at i=-30 degrees and a range of emission angles at 10 degree increments and show forward scattering behavior.

These preliminary results show that the instrument is capable of collecting photometric data for relatively bulky hand samples of intact, weathered surfaces (rather than being limited to small, powdered samples).

Conclusions: WWU's automated goniometer offers the capacity to efficiently measure reflectance spectra at a range of viewing geometries relevant to spacecraft data. By facilitating the characterization of viewing geometry effects for rocks and minerals relevant to planetary surfaces, this instrument will better enable direct comparisons between spacecraft data and laboratory spectra collected at the same viewing geometry. This will both enable more precise interpretation of spacecraft data by eliminating one potential source of error, and also open the door to new insights based on observations of spectral dependence on viewing geometry. We make the hardware design and control software available to the community to help facilitate efficient spectrogoniometric data collection in other laboratories.

References: [1] Ehlman et al. (2012) *JGR*, 117, E00J16. [2] Grotzinger et al. (2013) *Science*, 342. [3] Jackson et al. (1992) *Remote Sensing of Environment,* 40, 3, 231-239. [4] Cloutis et al. (2006a) *LPS XXXVII*, Abstract #2121. [5] Rudolph et al. (2017) *GSA*, Paper No. 276-2