INTERLABORATORY COMPARISON STUDY OF VISIBLE AND NEAR-INFRARED REFLECTANCE SPECTRA USING A SET OF COMMON STANDARD MATERIALS. T. Hiroi[1], S. Sasaki[2], M. Okazaki[2],M. Matsuoka[3], Y. Sato[3], T. Nakamura[3], Ralph E. Milliken[1], Carlé M. Pieters[1], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA (takahiro_hiroi@brown.edu), [2]Department of Earth and Space Sciences, Osaka University, Toyonaka, Osaka 560-0043, Japan, [3]Department of Earth and Planetary Materials Sciences, Tohoku University, Sendai, Miyagi 980-8578, Japan.

Introduction: Visible and near-infrared (VNIR) reflectance spectroscopy has been a useful technique in obtaining compositional information of rocky surfaces of airless planetary bodies. Therefore, many laboratory studies employed various kinds of VNIR spectrometers to accumulate spectral data of common geologic minerals and the like. However, consistency or accuracies of their wavelength and reflectance values have not been often checked among different laboratories. This study is one of such efforts [1] employing four different instruments operated at three different laboratories.

Experimental: The standard materials used for this study were Spectralon (SRS-99-010) and a wavelength calibration standard (CSTM-WCS-MC) purchased from Labsphere. Bidirectional diffuse reflectance (BDR) spectra of the latter relative to the former were measured by four different spectrometers: Reflectance Experiment Laboratory (RELAB) [2, 3] BDR spectrometer, Bunko-Keiki spectrometer at Osaka University, Bruker Vertex 70v at Tohoku University, and ASD Fieldspec 3 at RELAB.

The average incidence and emergence angles were set to 30 and 0 degrees, and the incidence beam footprint sizes were 3±1 mm. The incidence and emergence cone angles are estimated as: 8 and 4 degrees for RELAB BDR, 13 degrees each for Bunko-Keiki, 12.5 and 25 degrees for Bruker, and 25 degrees each for ASD. The sample was spun for RELAB BDR and ASD measurements to average out possible heterogeneity around the azimuth axis.

The wavelength range was 350-2050 nm, and the sampling interval was 1 nm except for Bruker which sampled data at an interval that is half the wavelength resolution. The nominal wavelength resolutions were 2-8 nm for RELAB BDR, 5 nm for Bunko-Keiki, 0.25-3.2 nm (16-8 cm^{-1}) for Bruker, and 3-10 nm for ASD.

When neighboring spectral segments differ in reflectance due to different light sources or detectors, the side known to be more trustable was adopted and the other side was scaled/spliced to the former. In general, such discrepancies were only up to 5 % in reflectance.

Results: Shown in Fig. 1 are the entire spectra of WCS relative to Spectralon by four different instruments. In general, all the four instruments produced highly consistent reflectance spectra of the common standard pair of materials. There are up to 6 % reflectance scatters, and the RELAB BDR spectrum seems to represent the central value of all. Bunko-Keiki spectrum is very close to RELAB BDR one over the entire wavelength range, and Bruker and ASD spectra seem to have slightly bluer continua than RELAB BDR and Bunko-Keiki continua.

Another notable difference is their wavelength resolution variation as depicted in Fig. 2 over the visible range. Without adjusting their wavelength resolutions, wavelength positions cannot be compared. This issue is investigated using moving average operations below.

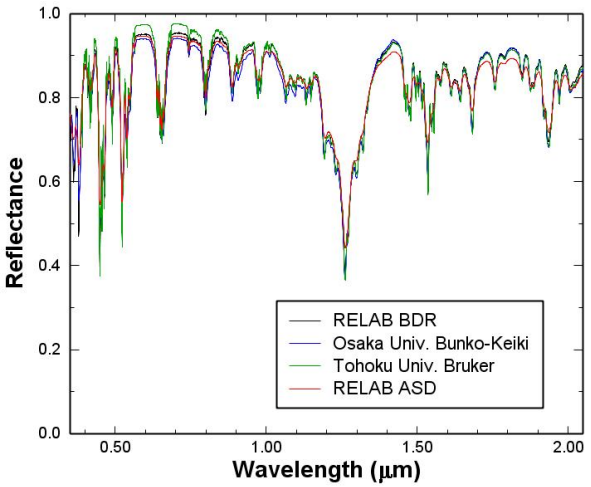

Fig. 1. Reflectance spectra of WCS relative to Spectralon measured by four different instruments.

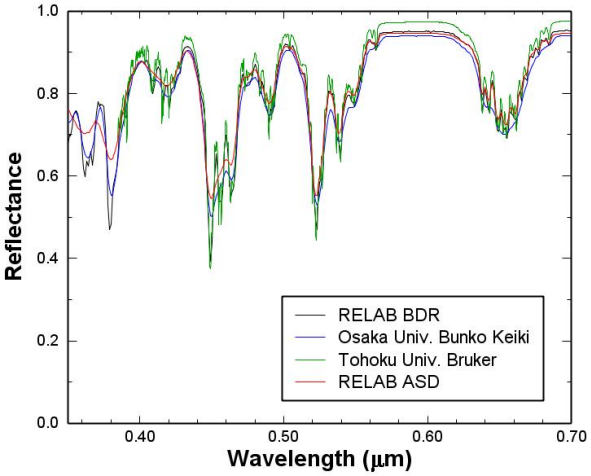

Fig. 2. An enlarged view of the visible range of the spectra in Fig. 1, depicting the wavelength resolution variation.

Wavelength Resolutions and Positions: Before comparing wavelength positions, resolution differences have to be examined and taken into account. As shown in Fig. 3, Bunko-Keiki spectrum is best matched with RELAB BDR spectrum that is moving-averaged over 7 data points. Assuming that RELAB BDR spectrometer truly has a 2 nm resolution, this result suggests that Bunko-Keiki spectrometer has a resolution of 8 nm.

In the same manner, as shown in Fig. 4, the mid-visible range of ASD spectrum is best matched with RELAB BDR spectrum that is moving-averaged over 7 data points. This suggests that ASD spectrometer has a 8 nm wavelength resolution in the mid-visible range, which decreased toward the shorter wavelengths and increased toward the longer wavelengths. An alternative explanation is that RELAB BDR and Bunko-Keiki spectrometers have variable wavelength resolutions over the visible range, that increase toward shorter wavelengths and decrease toward longer wavelengths.

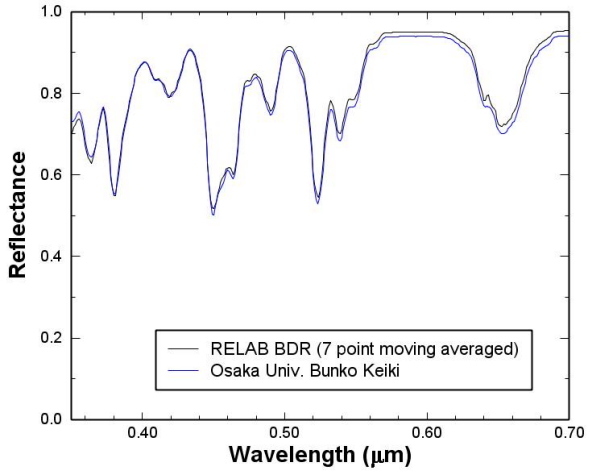

Fig. 3. RELAB BDR spectrum that is moving-averaged over 7 data points to match Bunko-Keiki spectrum.

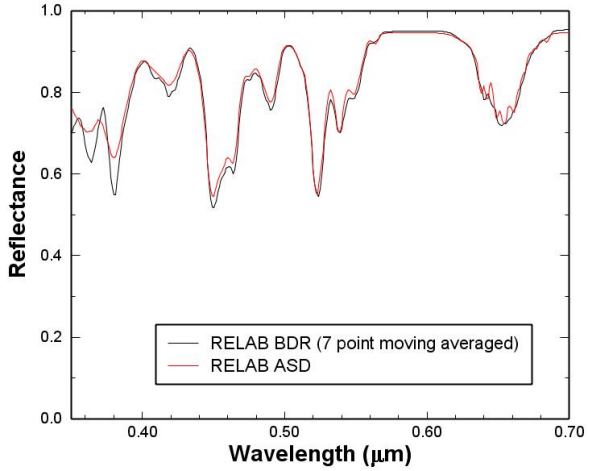

Fig. 4. RELAB BDR spectrum that is moving-averaged over 7 data points to match RELAB ASD spectrum.

Lastly, as shown in Fig. 5, RELAB BDR spectrum is best matched with Bruker spectrum that is moving-averaged over 9 data points. Because Bruker sampled at double the frequency of its wavelength resolution, this result suggests that at 500 nm (20,000 cm^{-1}), the RELAB BDR wavelength resolution is estimated to be

$$(16\ cm^{-1} \times 5) / 20000\ cm^{-1} \times 500\ nm = 2\ nm$$

which is consistent with its nominal resolution. Because the wavelength resolution of Bruker is constant at 16 cm^{-1} in wavenumber over this visible range but is variable in wavelength, the excellent match in Fig. 5 suggests that RELAB BDR also has a variable wavelength resolution centering on 2 nm around 500 nm in wavelength, increasing toward shorter wavelengths and decreasing toward longer wavelengths. This is consistent with the result in Fig. 4 as discussed above.

After taking care of these wavelength resolution differences, wavelength positions appear to be consistent within 2 nm between RELAB and ASD, and within 1 nm between RELAB and Bunko-Keiki or Bruker.

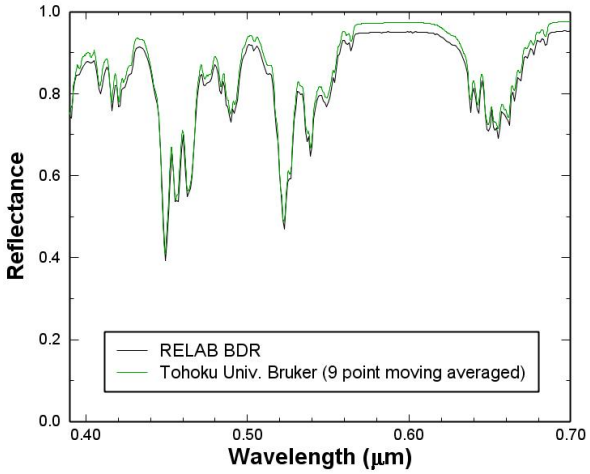

Fig. 5. Bruker spectrum that is moving-averaged over 9 data points to match RELAB BDR spectrum.

Summary: As a result of measuring the relative VNIR spectra of a pair of standard materials by four different spectrometers, a high level consistency in both reflectance and wavelength position has been obtained, except for the ASD which is known to show some wavelength position deviations [1]. Among the three highly-consistent spectrometers, RELAB BDR spectrometer have shown the average reflectance and continuum slope values of the other two spectrometers.

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References: [1] Mann P. (2014) *LPS XLV*, Abstract #2392. [2] Peters C. M. and Hiroi T. (2004) *LPS XXXV*, Abstract #1720. [3] RELAB home page: http://www.planetary.brown.edu/relab/.