# Characterization of a portable, fiber-optic coupled spectroradiometer as a transfer radiometer for the calibration of the Robotic Lunar Observatory

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**Abstract**. We report on the characterization of a portable, fiber-optic coupled spectroradiometer. The system was tested for radiometric stability and repeatability, wavelength calibration, stray light, linearity with optical flux, and sensitivity to ambient temperature. Many of the measurements were performed using the NIST laser-based facility for Spectral Irradiance and Radiance responsivity Calibrations using Uniform Sources (SIRCUS). The goal of this work was to understand the performance of the instrument as a transfer radiometer, with specific application to the *in situ* calibration of the Robotic Lunar Observatory (ROLO) in Flagstaff, Arizona. Characterization issues that apply to spectral reflectance determinations of vicarious calibration sites were also investigated.

## Introduction

The Robotic Lunar Observatory (ROLO) acquires radiometric measurements of the Moon in selected spectral bands between 345 nm and 2390 nm in order to provide a stable, well-calibrated reference standard that can be observed from orbit by multiple Earth-observing satellites (Kieffer and Wildey 1996, Kieffer and Stone 2005). The radiometric calibration is based on Vega. In 2003 the National Institute of Standards and Technology (NIST), the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC), the University of Arizona (UA), and the U.S. Geological Survey (USGS) collaborated to design and execute an independent calibration using a collimated source that directly illuminated the ROLO systems. To establish the stability of the source at the focus of the collimator during the measurements, a portable, fiber-coupled spectroradiometer was used to periodically compare the output of this source to that of a stable, laboratory reference standard.

## Measurement Systems

The transfer spectroradiometer was a portable, fiber-optic coupled commercial system manufactured by Analytical Spectral Devices, Inc. (ASD) of Boulder, Colorado. The Hydrospheric and Biospheric Science Laboratory at NASA/GSFC uses this ASD FieldSpec® Pro (serial number 6172) in instrument studies and occasional field exercises. The instrument consists of three separate systems that cover the spectral range from 350 nm to 2500 nm: a single grating spectrograph with a linear Si diode array and two single grating spectrometers, each with an InGaAs detector. Three optical fiber bundles, which are joined on the input side, channel light from the source to each of the three dispersing systems. In this instrument, the option of thermoelectric cooling of the Si array is installed, and we operated with the cooling on. Because of the wide spectral range and light weight, instruments in this product line are often used for *in situ* reflectance, radiance, and irradiance studies as part of vicarious calibration experiments.

At NIST, lamp illuminated integrating sphere sources, a custom five-channel filter radiometer, and the laser-based facility for Spectral Irradiance and Radiance responsivity Calibrations using Uniform Sources (SIRCUS) were the primary instruments or facilities used to characterize the ASD prior to the field measurements at ROLO.

## Preliminary Results at ROLO

The repeatability and stability was tested using an Optronic Laboratories OL455 integrating sphere source in a laboratory environment. The ASD was aligned to view the exit aperture (7.6 cm diameter) normal and centered. A five-channel visible filter radiometer (Allen *et al*. 2003) was used to monitor the output of the OL455 by viewing the center of the exit aperture at an angle. Independent measurements were made on five days, with full power cycling of the ASD and the OL455 but no changes to the optical alignment. Excluding spectral regions with known atmospheric features, the within-day stability was <0.3 %. The repeatability with the ASD over the five days is shown in Fig. 1; excluding the atmospheric features, the repeatability is within +/- 0.3%. The filter radiometer, which has temperature-stabilized filters, also gave results within +/- 0.3% for the channels from 550 nm to 900 nm. Thus, the minimum uncertainty for assessing the stability of the ROLO source in the field calibration is 0.3%.

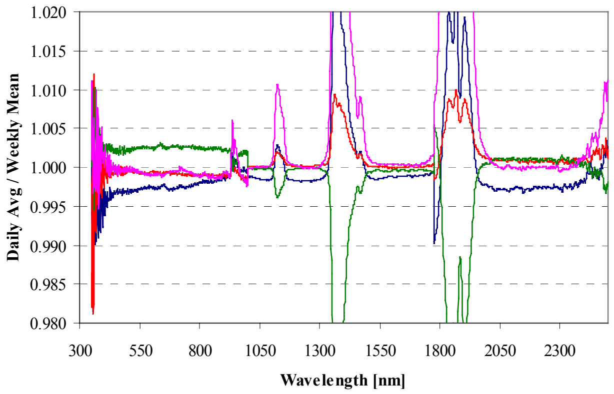


**Figure 1.** The repeatability of the ASD as determined at NIST using the OL455 source. Each day, data were acquired for 1 h after a determined warm-up interval.

During the field exercise at ROLO, the ASD was used to measure the radiance of the custom USGS source that was mounted at the focus of a spherical mirror. This was outdoors under varying environmental conditions. During the intervals when the ROLO telescope was observing the collimator source, the ASD was used to measure the NIST Portable Radiance (NPR) source (Brown and Johnson 2003), which was located indoors. One example of the results, for the lowest level of the ROLO source, is shown in Fig. 2. Illustrated is the ratio of the results for the two sources, normalized to the average. Based on these data, the stability of the ROLO source was <0.5% from about 450 nm to 1000 nm, <1% from 1000 nm to 1700 nm, and <3% from 1700 nm to 2450 nm.

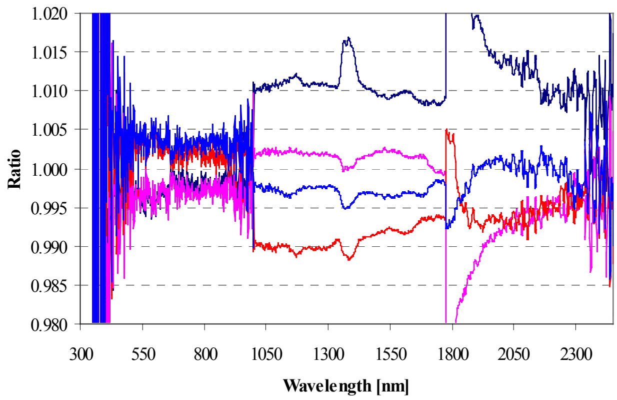


**Figure 2.** The results of sequential measurements of the ROLO source and the reference source during the course of one night's experiment in Flagstaff.

It is not unexpected that the repeatability of the transfer between the ROLO source and the NPR is not as satisfactory as the results obtained in the laboratory with a single source. Sensitivity to alignment, which depends on the field-of-view of the ASD systems (used in bare fiber mode), sensitivity to ambient temperature, and the dynamic range of the ASD are all factors.

## Application to Land Reflectance Studies

Portable spectroradiometers such as those described here are used in spectral radiance mode to measure solar-illuminated natural targets such as the Railroad Valley Playa in Nevada at the time of a satellite overpass (Thome 2004). The instrument is calibrated during the course of the day using a white, diffuse, reflectance standard. Additional characterization issues become critical, such as linearity, spectral out-of-band response, and wavelength calibration.

The spatial imaging of monochromatic light for the visible spectrograph was determined using tunable and fixed frequency lasers on the SIRCUS facility. Sample results are shown in Fig. 3, where the normalized response along the detector array for monochromatic excitation in the red is illustrated. In order to compare the shape of the response for regions away from the image of the entrance slit, the results are referenced to the pixel with maximum response. A reasonable explanation for the broad shoulder is interreflections within the detector array.

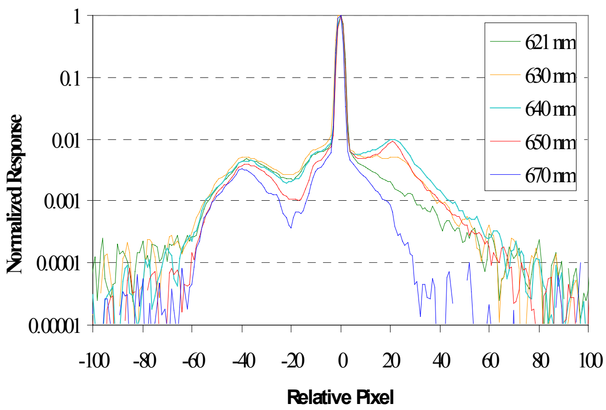


**Figure 3.** Normalized relative spatial scans for the visible and near infrared spectrograph in the ASD.

## Summary

An ASD FieldSpec® Pro was characterized and used to establish the stability of the ROLO source during field calibrations. We will also report on additional characterization results and their significance regarding vicarious calibration experiments.

## References


Certain commercial equipment, instruments or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment are necessarily the best suitable for the purpose.

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