**An Algorithm For Estimation And Correction Of The Thermal Emitted Radiance With Preservation Of Spectral Structure In Data Measured By The Moon Mineralogy Mapper.** R. O. Green**,** J. Boardman[2]**,** C. M. Pieters[3], Roger Clark[4], and The M3 Team. Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109 (Robert.O.Green@jpl.nasa.gov), [2]AIG , [3]Brown University, [4]U.S.G.S

Introduction: The Moon Mineralogy Mapper[1] (M^3) is a high uniformity and high signal-to-noise ratio imaging spectrometer that is a guest instrument on the Indian Space Research Organization (ISRO) mission to the Moon. The space flight portion of the mission ended on 27 August 2009. Over the course of the mission M3 measured spectral covering over 95% of the surface of the Moon. Efforts directed toward characterization, calibration and analysis of the M3 data are ongoing.

M3 measurements span the spectral range from 406 to 2991 nm with 9.98 nm sampling. Under direct illumination, the temperature of the lunar surface may approach 400°K. At these temperatures, the long wavelength portion of the M3 spectra includes both reflected and emitted radiance. Figure 1 shows an M3 image that from the Apollo 15 landing site region adjacent to Hadley Rille. Also shown are four spectra extracted from this data set. The spectra are shown as measured radiance and derived apparent surface reflectance with no thermal radiance correction. Spectrum 2 and 4 show a significant emitted radiance component that is expressed as a rapid rise in signal to the long wavelength end of the spectral range. This work investigates algorithms for retrieval of the temperature, reflectance and emissivity from M3 spectra that may be used to correct for the emitted radiance and recover the underlying spectral structure. This work builds upon many previous efforts[123].
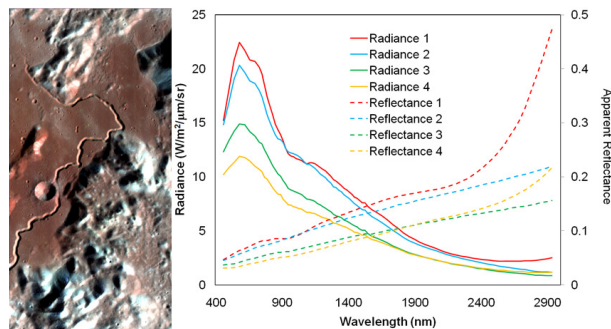

Figure 1. M3 image and measured radiance spectra near the Apollo 15 landing site showing the effect of emitted radiance for hot surfaces of the Moon in the long wavelength end of the M3 spectral range.

Measured Signal: The total radiance measured by M3 is given in Equation 1.

$$L_T(\lambda) = \rho(\lambda)F_0(\lambda)\cos_i/\pi + e(\lambda)B_0(T) \qquad \text{Eq. (1)}$$

For this equation, L_T is the total radiance, (λ) indicates function of wavelength, ρ is surface reflectance, F_0 is the solar irradiance, $\cos_i$ is the cosine of the solar incidence angle, e is the surface emissivity, and $B_0(T)$ is the Planck function radiance as function of temperature.

To assess the portion of the spectrum effected by emitted radiance a series of Planck function have been calculated for temperatures from 200 to 500°K. Figure 2 show a set of these modeled Planck spectra. From this analysis, the M3 spectral range is impacted by thermal to ~1800 nm for surfaces of 400°K temperature. The impact is less for lower temperatures.
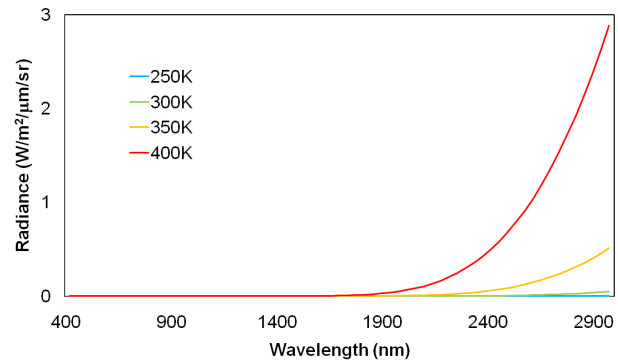
Figure 2. Planck functions for selected temperatures over the M3 spectral range.

Baseline Retrieval Algorithm: To separate the effects of thermal emitted radiance from reflected radiance at wavelengths longer than 1800 nm a non-linear minimization spectral fitting algorithms has been developed. The fitting routine used is the Downhill Simplex Method in Multidimensions[45]. The core merit function is given in equation 2.

$$E = |L_{TM}(\lambda) - L_{TE}(\lambda)| \qquad \text{Eq. (2)}$$

In this equation E is the absolute value error to be minimized, $L_{TM}(\lambda)$ is the measured total radiance and $L_{TE}(\lambda)|$ is the estimated total radiance. The estimated radiance uses equation 1 with the reflectance tied at 1800 nm based on an assumption of zero emitted radiance at this wavelength. The reflectance and emissivity for longer wavelength is projected as a linear function from this tie point.

This algorithm has been applied to the M3 Global Mode data set. Figure 3 shows a single wavelength image from 1818 nm and the derived surface temperature. The range of temperatures is consistent with those expected for the illuminated lunar surface. Using the results of this algorithm, Figure 4 presents the retrieved apparent surface reflectance in the absence of the emitted radiance component. In this spectrum, the long wavelength portion of the M3 spectral range shows recovery of the nominal surface reflectance shape beyond 1800 nm. A key drawback of this method is the assumption the surface reflectance and emissivity is a linear function extrapolated from the tie point near 1800 nm. In the presence of strong 2 micron or 3 micron absorption features this assumption is invalid.
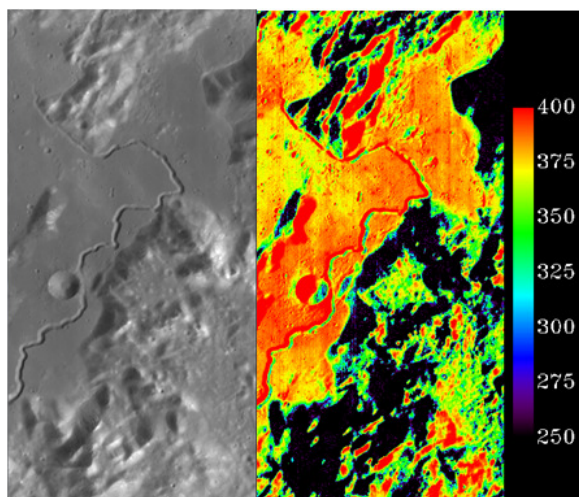
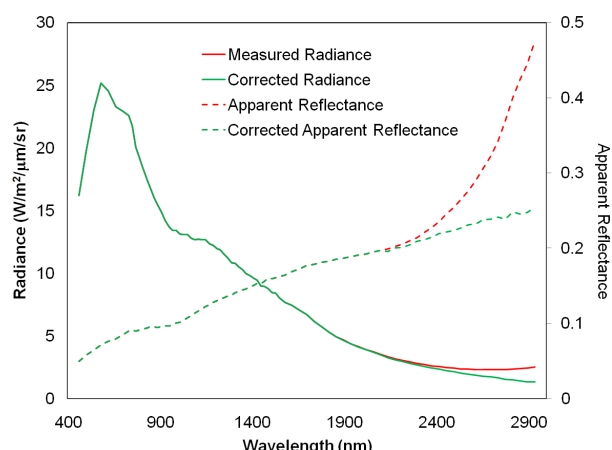Figure 3.   M3 image from 1818 nm and retrieved temperature derived with spectral fitting algorithm.

Figure 4.   Measured and calculated apparent reflectance before and after correction for surface emitted radiance.

Emitted Radiance Retrieval and Correction with Preservation of Spectral Structure: To accommodate the presence of surface spectral structure beyond 1800 nm this algorithm has been extended. The non linear fitting algorithm is capable of minimize a merit function when there are more measurements than unknowns. To allow for spectral structure in the region between 1800 nm and 3000 nm the surface reflectance is parameterized at every fourth spectral channels and then interpolated in the merit function. This approach allows the fitting algorithm to optimize the fit between the measured and estimated radiance while also allowing spectral structure that is variable beyond 1800 nm. Results of this algorithm for a 384k temperature spectrum are shown in Figure 5. The surface reflectance and emissivity are retrieved and in this case a weak upward bend in the reflectance is recovered from 2750 to 2950 nm. This is an important demonstration of this approach to retrieval and correction the emitted radiance component of M3 spectral while preserving spectral structure.
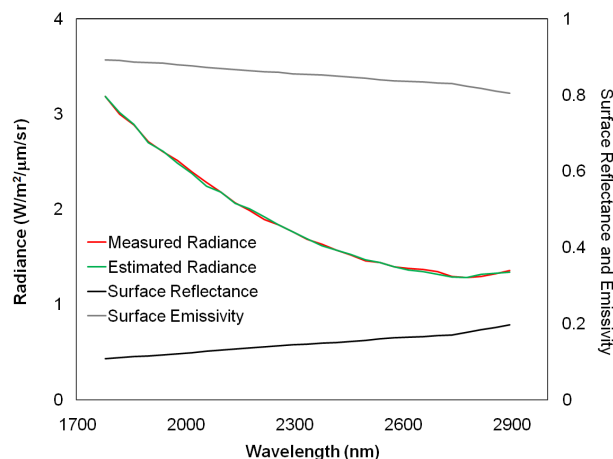

Figure 5 Initial test result of new spectral fitting algorithm for retrieval temperature, reflectance and emissivity with spectral structure in the 1800 to 3000 nm spectral region.

Conclusion: In the presence of high incidence solar illumination the temperature of the surface of the Moon is high enough to contribute significant emitted radiance to the spectra measured by M3. A simple non-linear spectral fitting algorithm to estimate and correct for the emitted radiance has been developed and tested with good success. A drawback in this simple method is the assumption of a linear spectral variation beyond the 1800 nm tie point. To overcome this drawback an enhanced algorithm has been developed that more accurately preserves the surface spectral structure beyond 1800 nm. Early testing of the enhanced algorithm has been successful. This novel approach offers the potential to accurately recover the spectral shape of 2 micron and 3 micron spectral features even in the presence of significant thermal emitted radiance.

Future Work: Use and testing of this algorithm has only recently commenced. Work with continue to refine and apply this algorithm to the large M3 data set and to explore the algorithms ability to more accurate recovery of spectral reflectance features in the presence of thermal emitted radiance.

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