THE EXTRATERRESTRIAL SPECTRUM FOR PLANETARY MAPPING: A LOOK AT OPTIONS FOR CHANDRAYAAN-1'S MOON MINERALOGY MAPPER. G. Y. Kramer[1], T. B. McCord[1], J. W. Harder[2], G. Thuillier [3], [1]*Bear Fight Center, Winthrop, WA, 98862, USA (gkramer@bearfightcenter.com)*, [2]*Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, Colorado 83030, USA*, [3]*Service d'Aronomie du CNRS, Verrires-le-Buisson, France*.

Introduction: The Extraterrestrial Spectrum (ETS) is the Solar Spectral Irradiance (SSI) on a surface at Air Mass Zero (AM0). It is the incident solar spectrum prior to distortion by terrestrial or atmospheric conditions. Its precise determination is of primary importance for converting radiance data from space-borne remote sensing instruments to accurate reflectance values necessary for geological interpretations.

Historically, the ETS has been determined by modeling, and removing, atmospheric interferences on a solar spectrum obtained by telescopic observations [1,2], aircraft [3,4], and ground measurements [5]. Over several years these models have been refined, and compiled [6,7,8], and are the basis for the ETS reference standards of the American Society for Testing and Materials (ASTM) [9,10].

Modeling an atmosphere is incredibly complex. Variations in local pressures, humidity, and particulate compositions present a many-bodied problem, and preclude a truly accurate representation of atmospheric conditions at any given time. This is somewhat apparent when one considers the reliability of the local weatherman's daily predictions. Although the ultraviolet and visible portion of the spectrum is virtually unhindered, several wavelengths in the petrologically significant infrared is replete with absorptions caused by the molecular vibrations of O_2, O_3, H_2O, and CO_2. The SSI measured from the ground, telescope, and even aircraft, all exhibit these spectral absorptions, so an ETS calculated from any of these must make some general assumptions about atmospheric conditions at the time of acquisition in order to compensate for their effects.

Objectives: In preparation for the launch of Chandrayaan-1, and subsequent influx of hyper-spectral data from the Moon Mineralogy Mapper [13,14,15,16], the M^3 team chose to reinvestigate the choice of the ETS that will be used to convert radiance data to reflectance. Since M^3 is a NASA/JPL instrument, the choice for an ETS was naturally one that the engineers are intimately familiar with; one they have been using for decades: MODTRAN.

MODTRAN (MODerate spectral resolution atmospheric TRANSsmittance algorithm and computer model) [11] is a Radiative Transfer Model (RTM) that is often used as the SSI for planetary missions, and is considered the "state of the art" RTM. MODTRAN models the effects of various atmospheric conditions on incident solar, surface radiant and reflected radiation. MODTRAN is an incredibly complex, high spectral resolution RTM, constantly being updated and improved upon since its evolution from LOWTRAN over 30 years ago. The model is robust, and well suited for Earth-based remote sensing systems. However, the accuracy of MODTRAN is dependent upon the accuracy of the fundamental, baseline ETS, which, with the exception of one [12], is a composite of several computationally-derived SSI (Fig. 1).

Although the ETS used in MODTRAN have been scrutinized by several peer scientists and engineers, and refined by decades of atmospheric measurements, they can never escape two fundamental problems: 1) the models that calculate the SSI at AM0 must make general assumptions about the atmosphere at the time the ground-, aircraft- or telescope-based measurements were taken; and 2) there are no regular measurements over time with which to monitor SSI variations. A true ETS would be best obtained by spacecraft orbiting outside the Earth's atmosphere, directly monitoring the Sun.

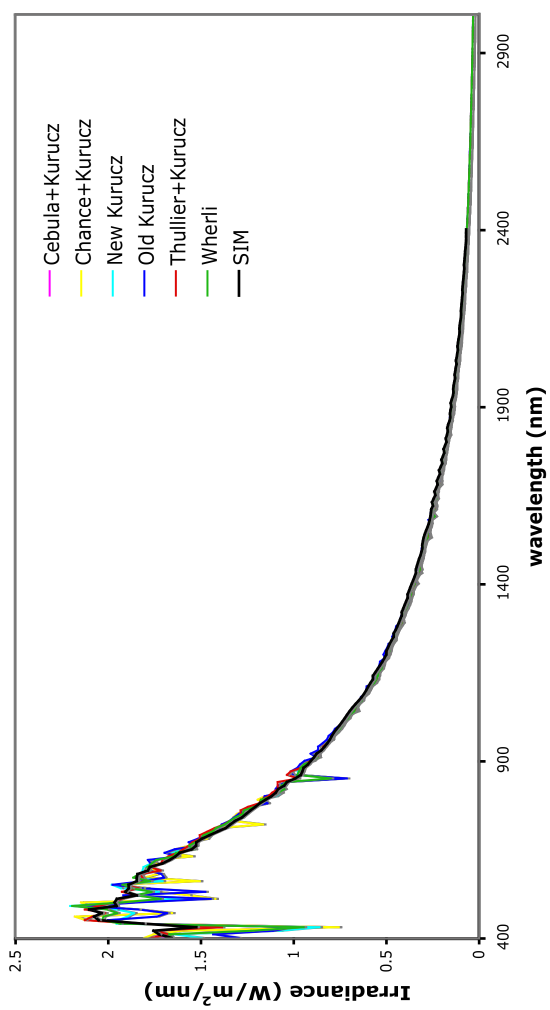

Figure 1: Various ETS used by MODTRAN resampled to M^3 spectral resolution and bandwidth.

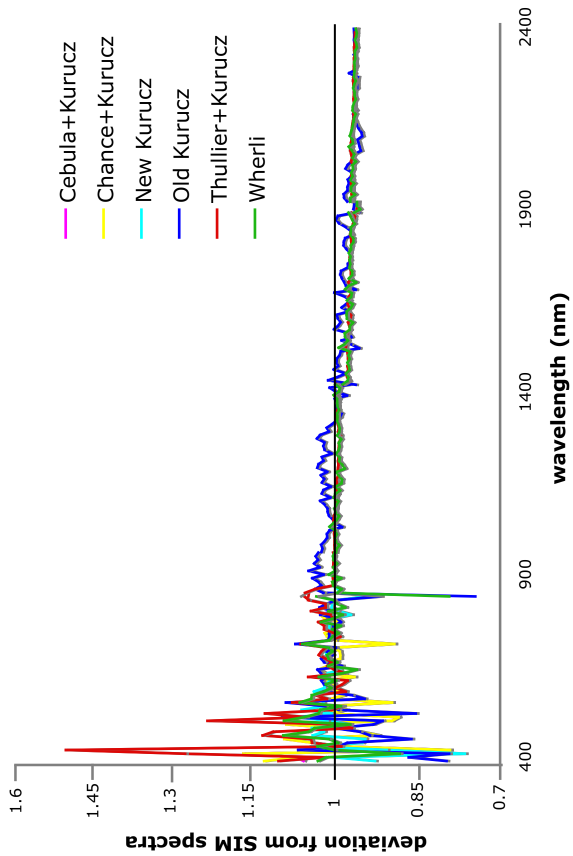

Figure 2: Deviation of ETS used in MODTRAN (see Fig. 1) from SIM spectrum (average of daily measurements of mission lifetime).

True ETS: Initial interest in obtaining direct measurements of the solar spectrum above the Earth's atmosphere was as an accompaniment to Apollo 17 lunar observations. Virtually all subsequent missions focused on the variable ultraviolet spectrum because of its importance for monitoring ozone and stratospheric circulation trends. However, this narrow range has little value in the context of planetary surface mapping, as most absorption bands diagnostic of mafic mineralogy are in the infrared.

SIM: In January, 2003 NASA launched the Solar Radiation and Climate Experiment (SORCE) [17], which carries the Spectral Irradiance Monitor (SIM) [18]. SIM takes daily measurements of the SSI at wavelengths between 310 and 2400 nm, with a spectral resolution better than 1 nm in the ultraviolet, 4 nm in the visible, and 12 nm in the infrared. SIM has thus far provided over 1500 ETS (and counting) that have been measured without atmospheric influence. In September, 2007 the SORCE mission was given a four year extension.

SOLSPEC: The ESA and CNES Solar Spectrum Measurement (SOLSPEC) instrument [12], which traveled on the ATLAS and EURECA missions in the early- to mid-1990s is one of first instruments to successfully acquire an extra-atmosphere SSI. SOLSPEC covered a spectral range of 200-2400 nm with a resolution of 1 nm in the ultraviolet and visible, and 20 nm in the infrared. Despite this sufficient spectral range, the SOLSPEC spectrum has been little used in planetary remote sensing. The latest incarnation of SOLSPEC is an externally mounted payload on the newest arm of the International Space Station, the Columbus laboratory. Once launched on board Atlantis early this year (2008), SOLSPEC will provide daily readings over potentially several years, and encompass the spectral range of 165-3080 nm [Thullier, personal communication].

Daily ETS and M^3: Daily measurements of the ETS has real significance for planetary missions. Monitoring solar spectral variations at Earth's orbital distance from the Sun has obvious applications for lunar missions, such as M^3. Over four years of daily ETS measurements by SIM has demonstrated that color variations can exceed 500:1; well within the sensitivity of M^3 [Pieters, personal communication]. One day's measurement of the lunar surface during a significant solar spectral change, could erroneously be interpreted as an anomalous feature on the lunar surface and/or bad acquisition by the instrument, if there were only one, constant SSI for calculating reflectance.

SOLSPEC and SIM also have an ally in M^3. Both instruments have their methods for calibration and monitoring of detector degredation. However, inflight calibration and instrument monitoring can also be checked by ground-truthing. Reflectance spectra from the Moon are relatively simple in that (compared with Earth) they are not altered by a variable atmosphere. Six Apollo missions and three Soviet Luna mission provided hand-samples that have been analyzed under laboratory conditions, and thus provide ground-truth locations.

Future planetary missions have a lot to gain from considering the extra-atmosphere-measured ETS of SOLSPEC and SIM. Fortunately, calculating reflectance does not require recalibration of data. Removing the SSI to convert radiance to reflectance is usually a last step, and can easily be recalculated. Therefore, past terrestrial, lunar, and other planetary spectral data can be reassessed with these current, and future extra-atmosphere-measured ETS.

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