Lunar Surface Material Composition Mapping

Introduction:

Japan, India, China, and the United States have recently sent spacecraft orbiters to study the lunar surface. The main focus of these missions has been to collect spectroscopic data that can be used to determine the surface mineralogy. This information is important for the planning of future lunar mining efforts and for determination of the most favorable locations for lunar bases – both manned and unmanned.

Techniques developed by the remote sensing community are routinely used to map land cover types on earth. Airborne and spaceborne sensors collect imagery in many wavelengths and principles of spectroscopy are combined with knowledge of relevant phenomenology to identify the material type present in each pixel of the image. In tropical regions, vegetation species may be identified. In temperate latitudes, vegetation, water, and soils may be differentiated. In desert regions, specific minerals such as alunite, kaolinite, and others may be identified and mapped.

This opens the possibility of mapping the mineralogy of the moon from earth. Several countries possess the necessary technology for sending a craft to the moon and returning it to earth with surface material samples. One can easily imagine that, prior to sending such a vehicle to the lunar surface, it would be desirable to know what to expect on the surface so that an optimal landing site could be chosen for sample retrieval.

Hyperspectral technology is ideal for the determination of material composition based on the reflectance spectrum from a known source of illumination, such as the sun. Exclusively an R&D technology in the 1990's, it is now widely available in both the academic and commercial communities. Routinely used to map the earth from aircraft and satellites, it could also be used to map the moon from earth.

Basic Requirements:

In order to produce lunar surface mineral maps, it would be necessary to satisfy the following six requirements:

1) A telescope capable of collecting enough light to allow examination of the spectrum

2) An imaging spectrometer capable of spreading the light into its wavelength components

3) A CCD at the focal plane capable of measuring the intensity of radiation at each wavelength

4) A computer with appropriate software to read out the CCD at appropriate intervals and store the data to disk

5) Software to examine and analyze the data collected

6) A spectral library that contains reflectance spectra of all minerals that are expected to be found on the lunar surface

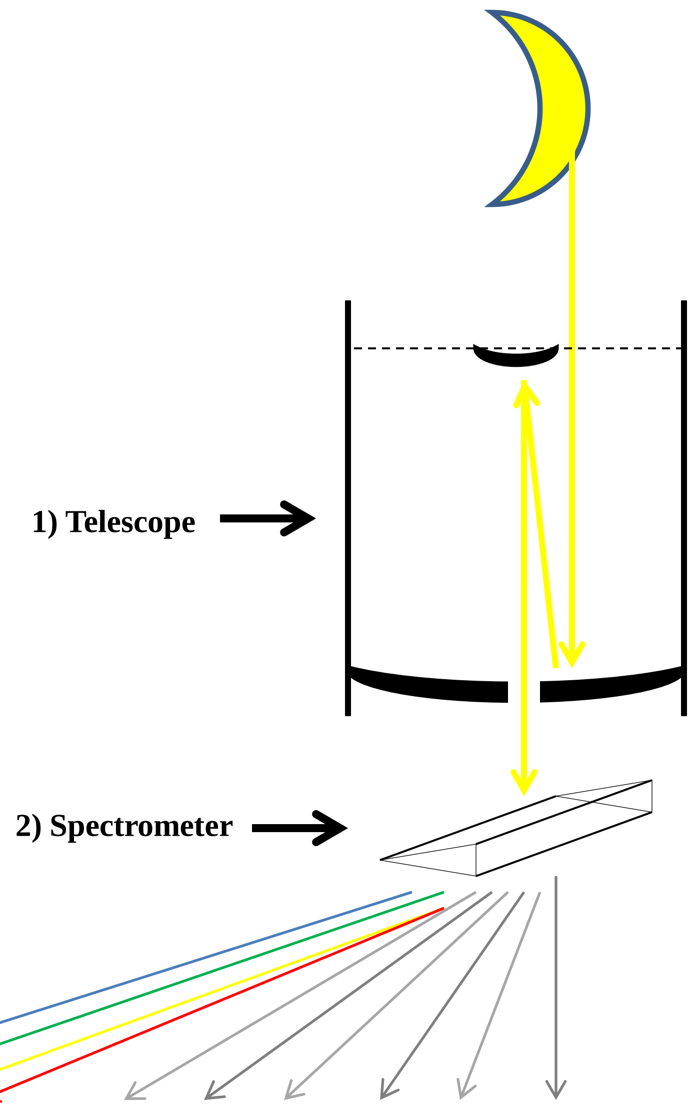
These six components are illustrated on the next page.

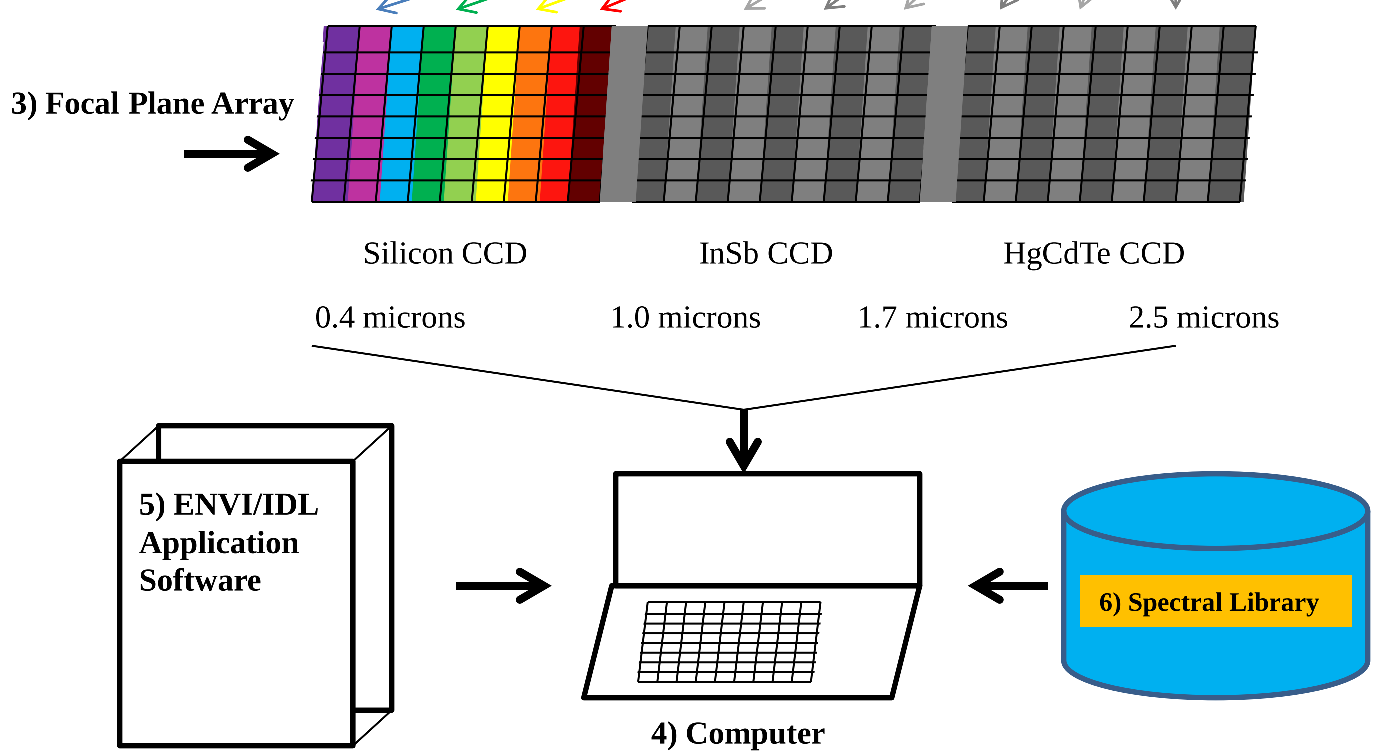
Photon to Photoelectron to Bits to Information

Flow Diagram

Light from the moon enters the 1) telescope, is separated into its component wavelengths by the 2) spectrometer, brought to focus on a 3) CCD detector array, which is read by application software on the 4) computer.

The computer also holds 5) ENVI software for spectral analysis and a 6) spectral library for surface material identification.





Technical Approach

We can examine each of the above requirements in more detail.

Proven hyperspectral technology uses a 2-D focal plane array (FPA) to spread a 1-D sample into its spectral components. That means that the radiation that would be recorded by one detector at the focal plane of a grayscale imager is spread over about 50 detectors. On average, each detector receives only about two percent of the incoming radiation. This creates a requirement for a large, fast primary optic in order to generate sufficient image scale while preserving signal.

The FPA acts as a scanning array, which means that a scanning motion is required. For earth remote sensing applications, the scanning motion is provided by aircraft or spacecraft motion. For astronomical applications the earth's rotation can be used. In the event that the rotation rate (15 arc seconds per second) is too fast, the clock drive mechanism at the GMU observatory can be adjusted to provide any scanning rate that is necessary to achieve good SNR. The required exposure time is inversely proportional to the amount of incident illumination, which is equal to the blackbody radiation emitted by the sun, as shown in Figure 1. For the visible region of the spectrum, earth's rotation rate will suffice. From the near infrared to 2.5 microns the solar illumination is a fraction of the amount in the visible. The somewhat slower required scan rate will be provided by adjusting the clock drive.

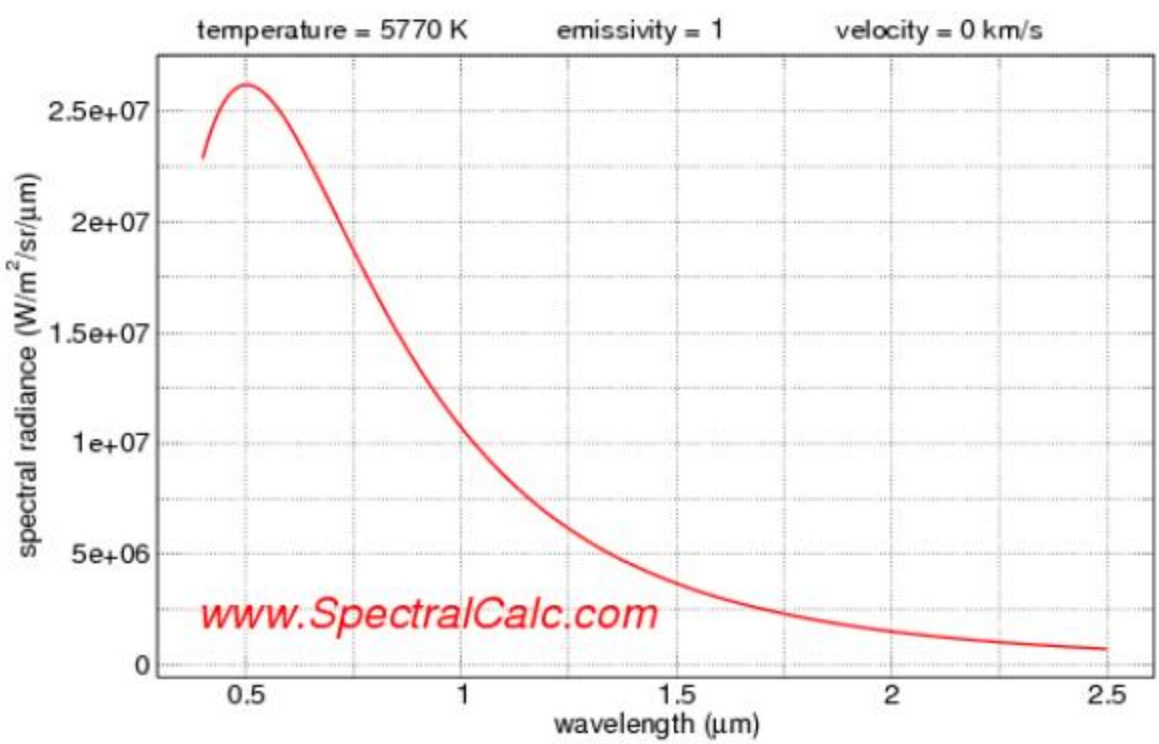


Figure 1

GMU already has a telescope of sufficient aperture to satisfy item 1). The 0.8 meter, f/7.2 instrument, in combination with a variable speed clock drive mechanism, collects enough light to achieve high SNR in any 10 nm spectral band from 0.4 to 2.5 microns, given an appropriate exposure.

Item 2) is a critical requirement. Available instruments vary widely in capability and cost. In general, spectrographs that cover the 0.4 micron to 1.0 micron spectral region are least expensive, and those that operate from 1.5 to 2.5 microns are most expensive. The earth remote sensing community often uses compound instruments that employ dichroic beamsplitters to take light from one source and divert appropriate spectral ranges to detectors that are capable of registering the incoming photons. The increased complexity and cost of this approach is prohibitive without government funding. For academic purposes, there is a requirement for a separate spectrometer for each of the three spectral regions that are defined by the limits of semiconductor technology. Silicon based CCDs are sensitive to light from about 0.4 to about 1.1 microns. InGaAs and InSb based CCDs are sensitive from about 0.9 to about 1.7 microns. HgCdTe based CCDs are sensitive from about 1.7 to 2.5 microns (the limit based on atmospheric water absorption).

Item 3) is actually composed of three distinct requirements. First, with least expense, coverage from 0.4 microns to about 1.0 microns may be satisfied by the use of a silicon based CCD detector array. At greater expense, coverage from 1.0 microns to about 1.7 microns can be achieved through the use of an InSb or InGaAs focal plane array. Low cost CCD imagers that detect from 1.5 microns to 1.7 microns are available from Edmund Scientific, but they leave the 1.0 to 1.5 micron range unobserved. Lastly, at greatest expense, the 1.7 to 2.5 micron region of the spectrum requires HgCdTe focal plane arrays which must be cryogenically cooled. For earth remote sensing requirements, the 2.0 to 2.5 micron region of the spectrum is critically important for mineral identification. Though not as critically important, it is also desirable for identification of reflectance spectra of the moon. Unfortunately, the moon presents an additional problem because its daytime surface temperature is high enough to add significant amounts of blackbody radiation to the signal received at wavelengths longer than 2 microns. Because of the high cost of HgCdTe detector arrays, the difficulties associated with cryogenic cooling, and the additional difficulties associated with separating and removing the reflective and the emissive signals in the longer wavelengths, it is recommended that this effort be confined to the 0.4 to 1.7 micron range of the spectrum.

Note that the current equipment inventory at GMU does not satisfy the requirement for a silicon based CCD detector. The SBIG STX-16803 CCD imager is driven by software that does not allow frame capture at a sufficiently rapid rate. The minimum frame capture requirement is on the order of 10 frames per second (fps), but the SBIG requires many seconds to download a single frame. The current line of Celestron Skyris CCD imagers offer capture rates that would satisfy this requirements at low cost.

The computer hardware requirement of item 4) is currently satisfied by GMU, but the software driver that operates the CCD imager is not satisfied. It would either be provided by the CCD supplier, or developed at GMU using an appropriate programming language, such as C. According to the technical literature, the current line of Celestron Skyris imagers may be provided with software that is completely satisfactory.

Item 5) is best satisfied by ENVI/IDL software. Widely used in the remote sensing community, it is licensed by the GIS department at GMU, and is available from Excelis.

Item 6) can be satisfied through use of the USGS spectral library. It may be accessed at the following site: http://speclab.cr.usgs.gov/spectral.lib06/ds231/datatable.html. A sample spectrum from the library is shown in Figure 2. Additional relevant information may be available in the ASTER, JPL, or JHU spectral libraries.

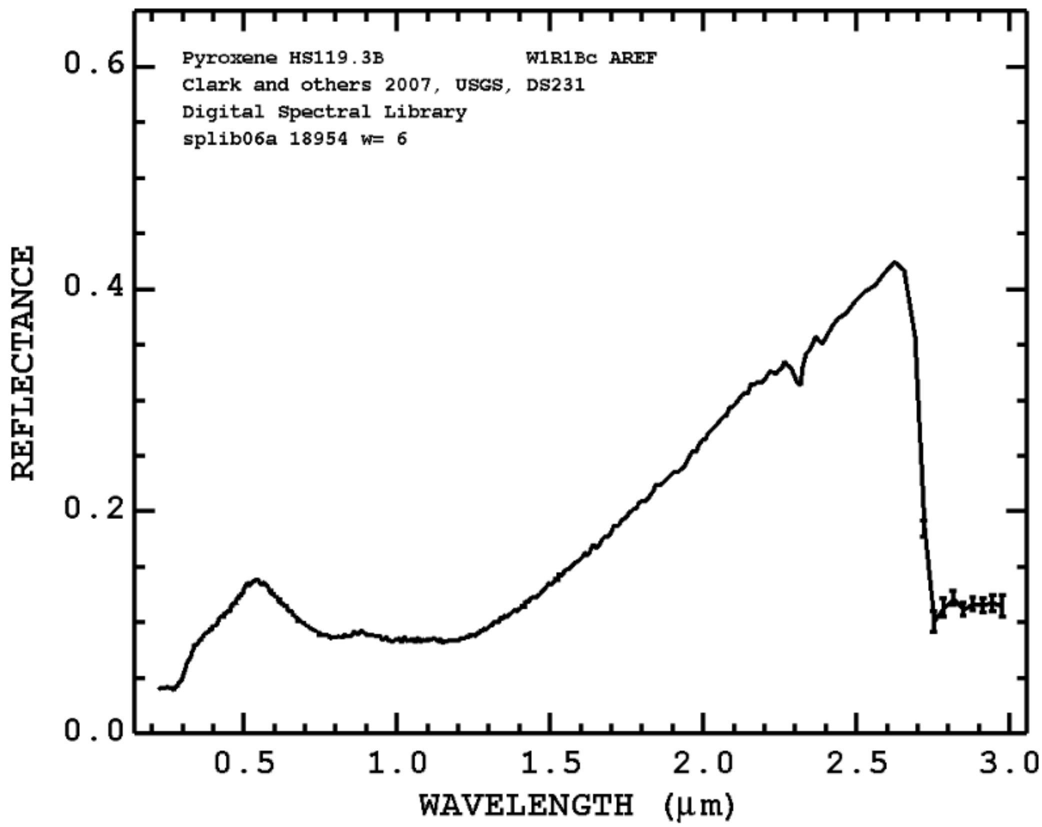


Figure 2

Conclusion:

Lunar mineral mapping is important to a number of nations, as evidenced by the recent rush of lunar orbiters designed to study the mineralogy of the lunar surface. Technology that has been proven to be successful in earth surface mapping was used on the orbiters, and may also be employed by earthbound observatories to study the surface of the moon. The observatory at GMU, if outfitted with appropriate spectrographic data acquisition and analysis equipment, could be used to map lunar surface minerals down to a scale of about one square mile. Required spectrographic data acquisition equipment includes spectral dispersion instrumentation and focal plane arrays that cover the 0.4 micron to 1.7 micron region of the spectrum, as well as software to drive the CCD electronics and analyze the collected data.   A phased approach for acquisition and implementation is possible, beginning with instrumentation to study the 0.4 to 1.0 micron spectral region, followed by instrumentation to study the 1.0 to 1.7 micron region. Lunar mineral mapping capability, if developed at GMU, would provide an outstanding educational experience for astronomy students. Once established, it could be used to determine the surface material composition of asteroids, including newly discovered earth grazers. The same capability could also be used to monitor planets such as Mars for subtle surface changes that are not visible in traditional color imagery, Jupiter and Saturn for changes in the molecular composition of their upper cloud decks, and other transient celestial phenomena.

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