Rick Evans' Amateur Lunar Photoclinometry, Spectroscopy, and Astrophotography

Studies of the Moon and some General Astroimaging

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Imaging Spectgrography (Multispectral and Hyperspectral Imaging)

I recently purchased a hyperspectral imaging system from the Brimrose Corporation (http://www.brimrose.com/) and it arrived the last week of February 2007. The imaging spectrometer takes a series of images between 500 nm and 1000 nm, separated by a user defined interval of about 5 nanometers or less. It uses an acousto-optical tunable filter, a Hitachi extended NIR videocam, and Brimrose software. It collects about 100 images in around 30 seconds or so, but averaging the results of multiple scans takes a bit longer. Collected images must be de-interlaced and I use Photoshop CS2 for this. The setup is shown below.

550 nm to 1000 nm Acousto-Optical Tunable Filter set up to take hyperspectral images of oranges

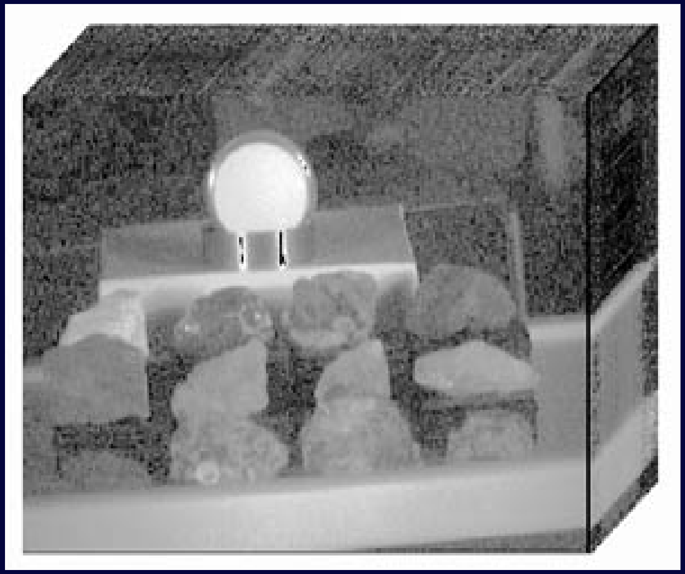
The Brimrose software doesn't calibrate images against a reflectance standard but it does show the signal to noise ratio of the images and the uncalibrated spectra for each image pixel. I've slowly become familiar with software used to analyze multispectral and hyperspectral images. I chose the freeware program TNTmips lite (see links submenu) which is a very comprehensive software package capable of creating hypercube images from multispectral and hyperspectral images. After de-interlacing, images are calibrated by dividing each image by the same fractional ratio of the greyscale value of the Spectralon standard obtained for the same wavelength. I use the freeware program ImageJ for this purpose. Calibrated images are saved as greyscale images in jpg format and are imported into TNTmips lite as an image group. The TNTmips lite program plots reflectance spectra for any pixel and offers many algorithms to view and classify these images. It will accept 640 x 480 pixel images. Unsupervised classification algorithms include principal component analysis and several other statistical methods. Supervised methods reference image spectra of features of known composition or library spectra.

Preliminary Studies:

To avoid initial complications with lunar tracking at high power and limited light, I began learning how to use the imaging spectrometer and analyze results by starting with still-life objects starting with a few pieces of fruit. My initial results are shown in the pdf file below.

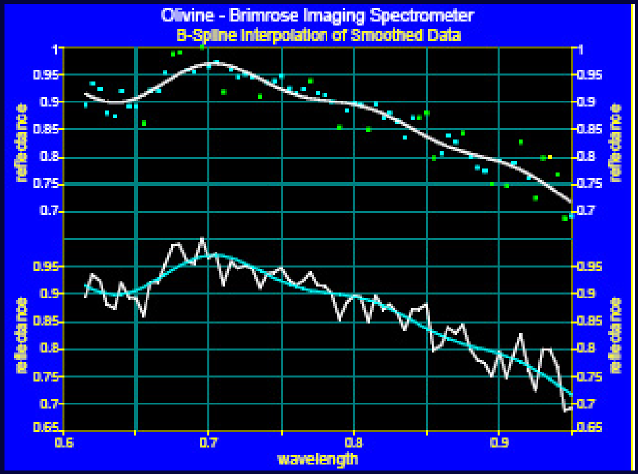
http://webzoom.freewebs.com/revans_01420/Hyperspectral/Brimrose-Fruit-1.pdf

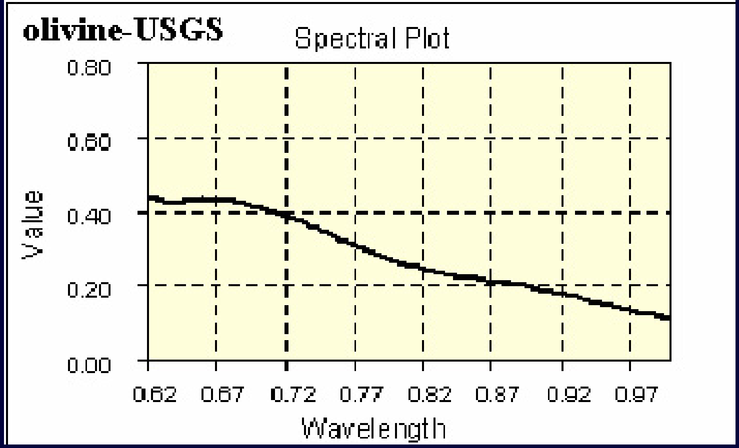
Next I tried to identify samples of olivine and malachite from the group of assorted rocks/minerals shown below. The left image is a color photograph while the right image is a representation of the hypercube composed of images from 450 nm to 900 nm in 5 nm increments.



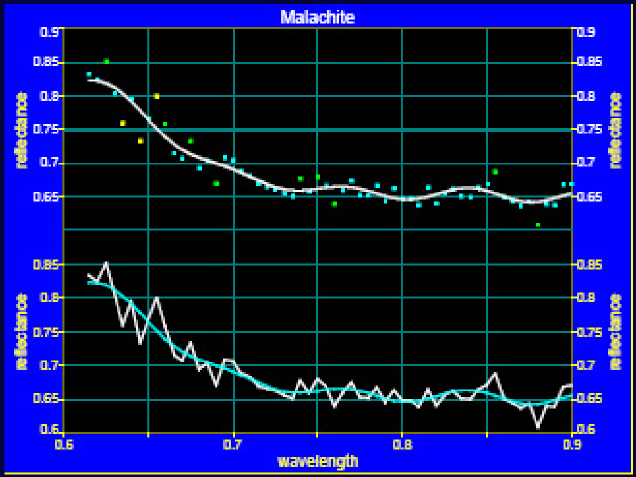
Color photograph of 12 rock/mineral samples **Hypercube Image**

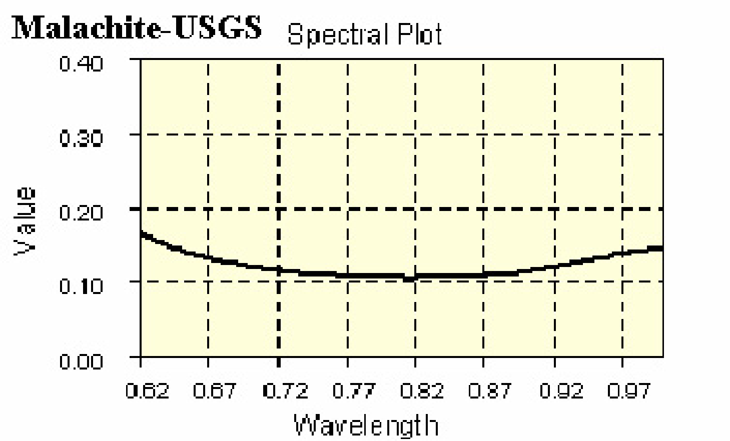
Spectra obtained from spectral analysis of the hypercube in TNTmips lite for olivine and malachite specimens are compared with spectra from the USGS spectral library in the figures below.





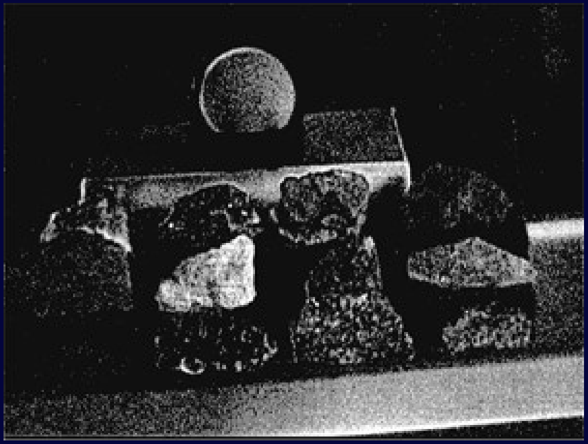
Olivine Sample (Hyperspectral Result) **Olivine Sample Result from the USGS Spectral Library**



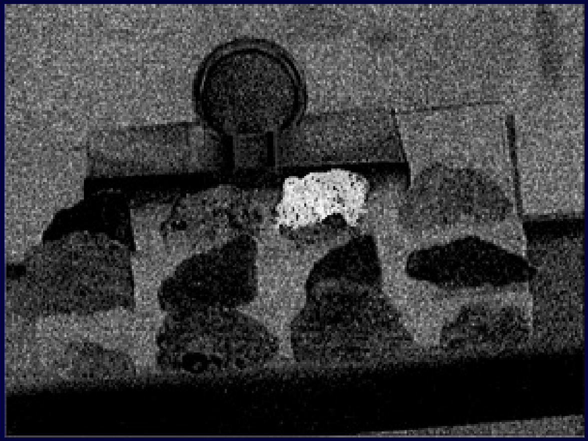


Malachine Sample (Hyperspectral Result) **Malachite Sample Result from the USGS Spectral Library**

The use of the Spectral Correlation matching algorithm in TNTmips lite to identify olivine and malachite samples from the group of 12 assorted rocks/minerals studied is shown below.



Spectral Match for Olivine



Spectral Match for Malachite

This demonstrates the usefulness of hyperspectral analysis in obtaining spectra and performing spectral matching for mineral spectra. It is anticipated that this technique will be helpful in studying lunar geologic features as the next phase of my project begins. For those that are interested in results for the remaining 12 rock/mineral samples, a pdf file is provided below.

http://webzoom.freewebs.com/revans_01420/Unprocessed Data/Minerals-Brimrose-IS.pdf

If you are interested in seeing differences between using the Brimrose Imaging Spectrometer and just using a collection of 58 individual interference filters, a study of much the same material using the individual filters is available below:

http://webzoom.freewebs.com/revans_01420/Hyperspectral/58FilterStudy.pdf

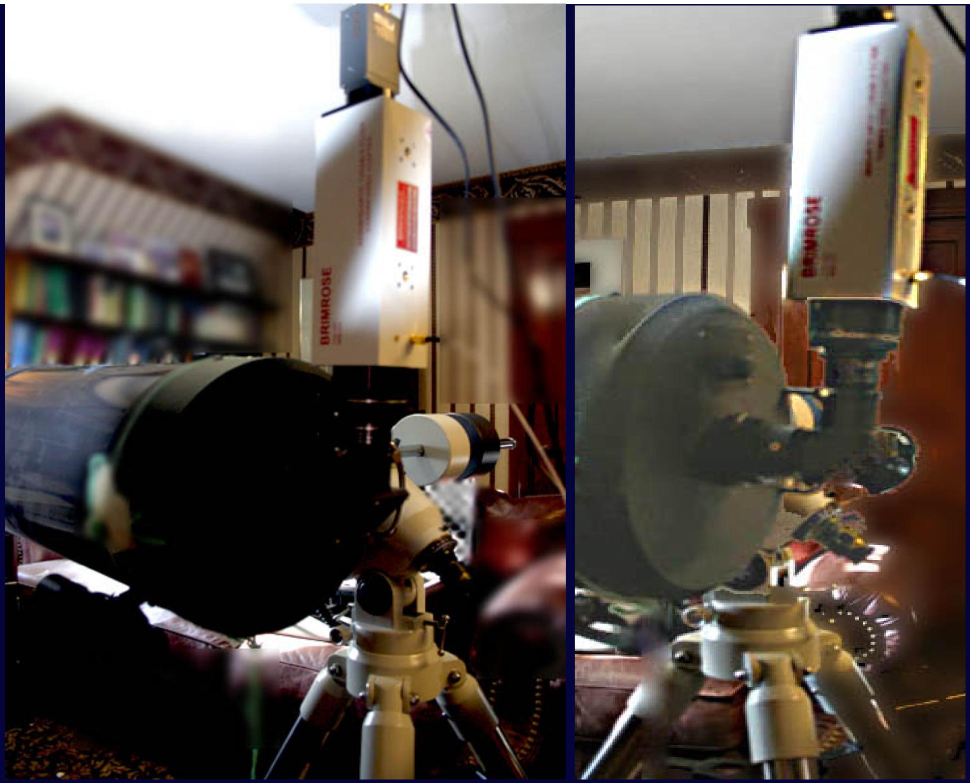
Technical Considerations for Lunar Hyperspectral Imaging:

The Brimrose imaging spectrometer can be attached to a spotting scope or an astronomical telescope using a standard T-adapter and a Nikon T-adapter ring as shown below. A star diagnonal is used with the telescope for stability.

Imaging Spectgrometer with T-adapter and Nikon T-adapter ring:

Imaging Spectrometer attached to a spotting scope:

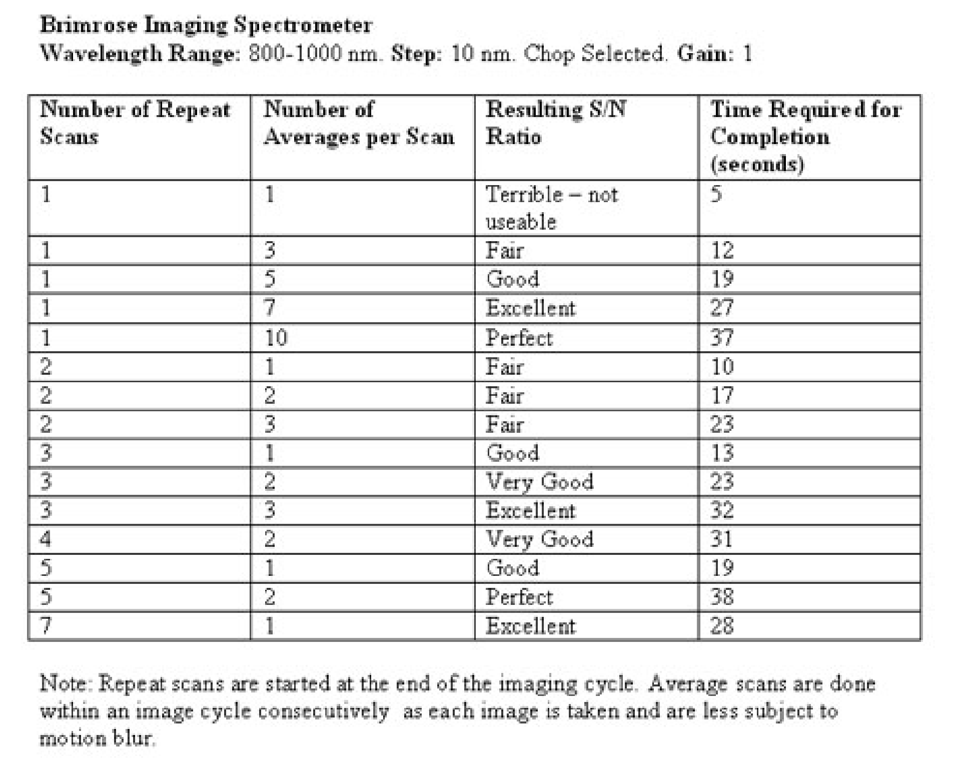
Imaging Spectrometer attached to a 9.25" F10 Schmidt Cassegrain Telescope:



The moon is a more challenging subject than still life objects such as the mineral collection imaged above. This is in part because 1) the moon has a maximal available brightness that is phase dependent and cannot be increased; 2) the moon must be magnified to show surface features in detail and this necessarily increases the F number of the exposures and the dimmness of the resulting image; 3) the moon is in constant motion and the effects of this motion increase with magnification; and 4) the moon must be imaged through the turbulence of the Earth's atmosphere. To have a reasonable chance of success using the Brimrose imaging spectrometer with a small telescope, it is therefore necessary to 1) image the moon close to full moon to maximize brightness; 2) image only under conditions of minimal atmospheric turbulence and no wind or haze; 3) to weight balance and accurately polar align the telescope to maximize tracking by a drive motor at lunar (not sidereal) rate; 4) to not exceed the maximum magnification at which tracking errors become unmanageable; and 5) to minimize the amount of time necessary for an image collection by the instrument to avoid tracking errors and 6) to be aware of water vapor absorption bands in the Earth's atmosphere.

The signal to noise ratio is maximized by using the chop feature in the Brimrose software for noise reduction and either averaging each pixel in a series of individual images taken at the same wavelength (i.e. averaging), combining images from multiple scans (i.e. repeat scanning), or a combination of both. The drawback is a prolongation of the imaging time required. For an object experiencing some positional drift, repeat scanning is a bad idea because scans are not repeated until the end of each imaging cycle. This can lead to substantial blur within each individual image. Repeat scanning, therefore, should only be used on subjects that are not in motion. Pixel averaging, on the other hand, is more advantageous because it is done by rapidly obtaining multiple images at a particular wavelength before the instrument then moves on to the next wavelength. So, averaging is completed when the imaging cycle is completed. This produces much less blur within an individual image as the time required for averaging at a given wavelength is much less than the time required for an entire imaging cycle to complete and a repeat scan to then be obtained at that point.

The total imaging time can also be offset to some extent by narrowing the range of wavelengths to a useful subset within the overall 500 to 1000 nm instrument range. To study the pyroxene iron reflectance trough it would be sufficient to set the range at 800 nm to 1000 nm. Total imaging time can additionally also be offset by increasing the image interval which for still-life objects would normally be between 2 and 5 nm. This interval can, for example, be set at 10 nm, 20 nm or 50 nm to further reduce imaging time. I created the chart below to look at the relationship between scan time and signal to noise ratio for various numbers of repeat scans and scan averages.



Brimrose Imaging Spectrometer
Wavelength Range: 800-1000 nm. **Step:** 10 nm. Chop Selected. **Gain:** 1

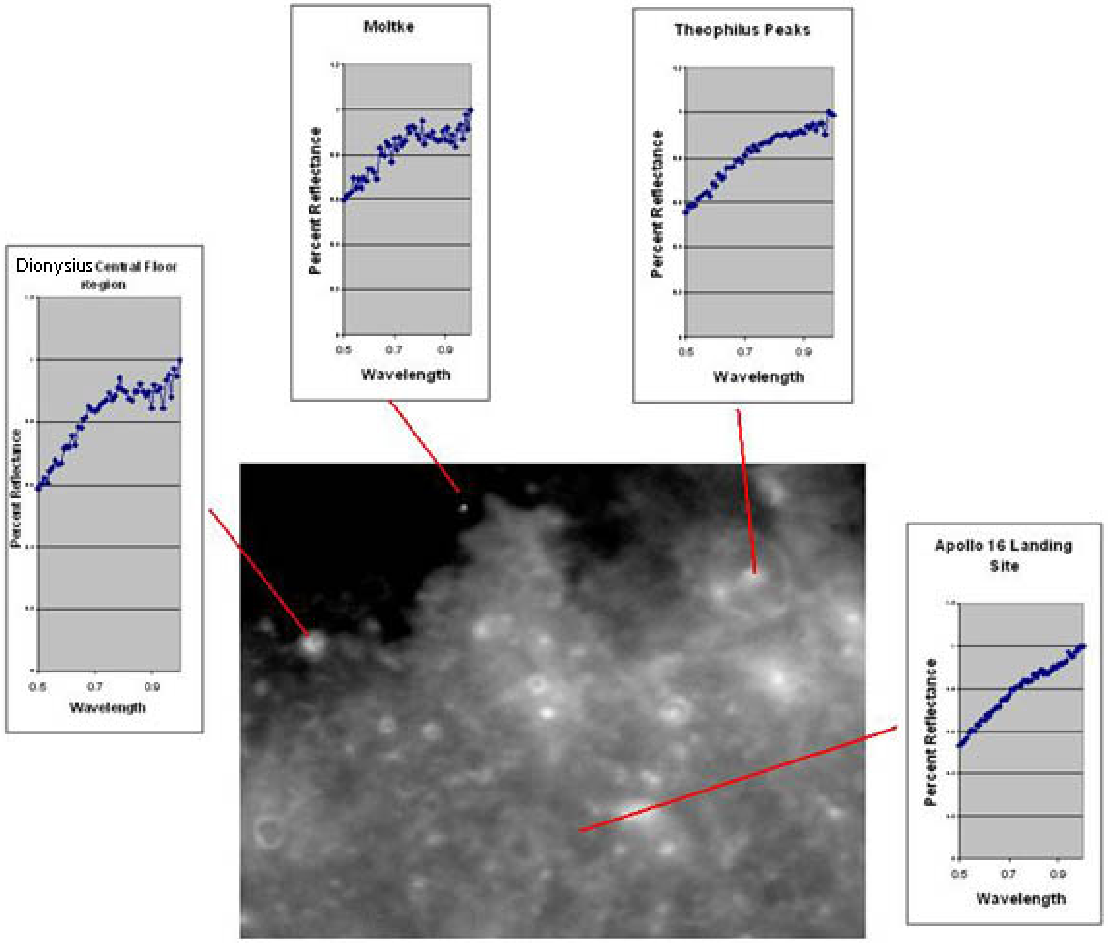
Number of Repeat Scans	Number of Averages per Scan	Resulting S/N Ratio	Time Required for Completion (seconds)
1	1	Terrible – not useable	5
1	3	Fair	12
1	5	Good	19
1	7	Excellent	27
1	10	Perfect	37
2	1	Fair	10
2	2	Fair	17
2	3	Fair	23
3	1	Good	13
3	2	Very Good	23
3	3	Excellent	32
4	2	Very Good	31
5	1	Good	19
5	2	Perfect	38
7	1	Excellent	28

Note: Repeat scans are started at the end of the imaging cycle. Average scans are done within an image cycle consecutively as each image is taken and are less subject to motion blur.

It appears to me that the best strategy is to use multiple pixel averages using only a single scan. I am hopeful that setting the wavelength range at from 800 to 1000 nm and defining the step interval at 10 nm should allow imaging with an acceptable signal to noise ratio in 27 to 37 seconds total imaging time. Most of this time is needed for image averaging since without averaging the total imaging time would be only 5 seconds. However, since the time required per image is only 27/20 to 37/20 seconds (i.e. 1.35 to 1.85 seconds), image blur should be quite minimal if tracking is even fairly reasonable. The reason to keep the total imaging cycle as short as possible is simply to minimize the pixel offset between the first and last image taken. However, this is not too critical a problem since the images can be co-aligned at a later date. It should be possible to reduce the interval between consecutive images to 5 nm. This will not cause additional blurring of individual images which will still be obtained at between 1.35 and 1.85 seconds. However, it will double the time for the entire imaging cycle and this will result in the need to correct a greater pixel position offset between the first and last image when subsequent co-alignment is performed. At prime focus (about F10) it should be possible to keep tracking errors to a minimum with careful polar alignment and use of a lunar rather than a sidereal tracking rate. Obviously, some practice will be required.

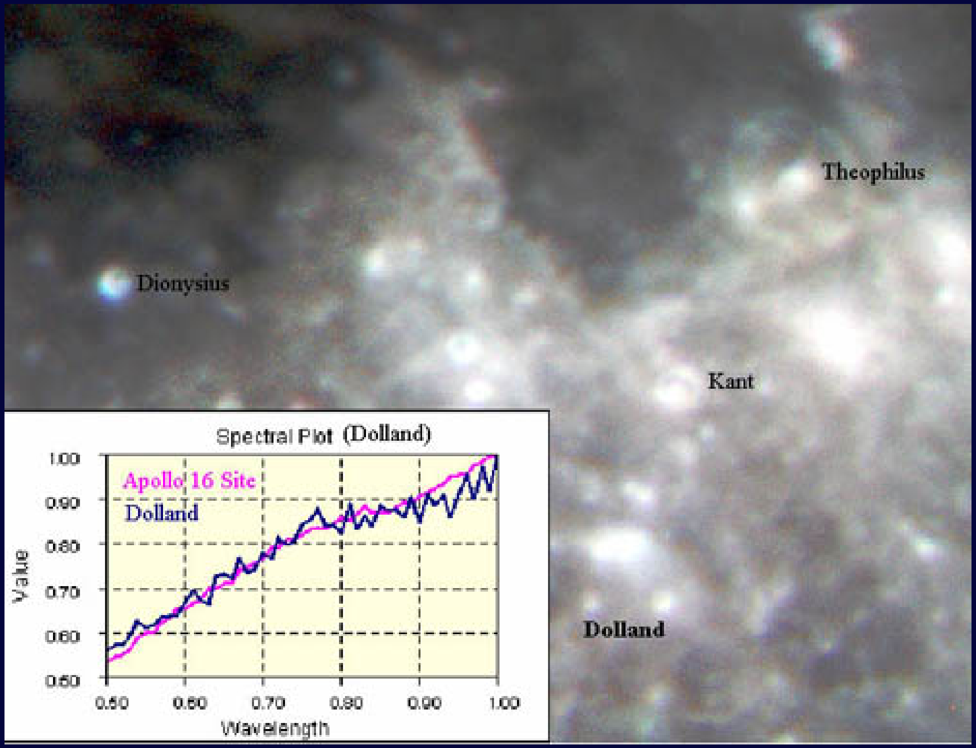
My First Lunar Imaging Spectrometry Results:

On March 30, 2007 and April 1, 2007 the weather finally allowed me to perform hyperspectral imaging runs near full moon under good weather conditions. I was able to obtain excellent calibrated spectra between about 640 and 920 nm. The resulting curves matched professional efforts very well. However, the Hitachi KPM2R camera was not capable of producing useful results with the Brimrose imaging spectrometer at wavelengths greater than 920 nm even at full moon. The camera lacked sufficient sensitivity. Unfortunately, the most useful wavelengths for lunar spectral analysis of mafic materials are in the 900 to 1100 nm range. Therefore, it was necessary to find a more sensitive camera. I purchased a Goodrich SU320MX-1.7RT camera in May of 2007. This camera uses an Indium-Gallium-Arsenide chip. I plan to use it initially with a set of 10-18 nm bandpass filters covering its range, but hope to eventually get a Brimrose 900-1700 nm AOTF camera adapter for it. Meanwhile, I also continue to get very good multispectral data using a set of 50 interference filters covering the range between 500 and 1000 nm at 10 nm intervals. The spatial resolution using these filters as a group can be very good and reasonable spectra can be obtained as shown below in an imaging run that I did on April 1, 2007 at 0200 UT. Although time consuming and inconvenient to perform, manual imaging with a large group of filters does have the advantage of producing images with a better overall quality than is achievable with a tunable filter.

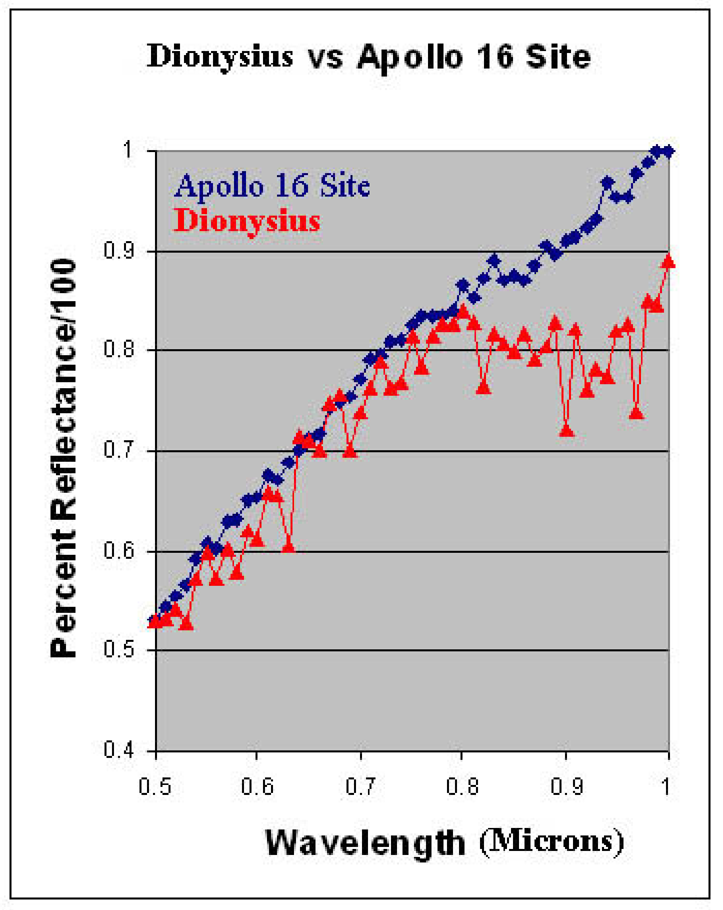


Multispectral Analysis of Theophilus Region. April 1, 2007 0200 UT. 500-1000 nm, 50 filters of 10 nm bandwidth. 9.25" F10 SCT. Lumenera 075M camera.

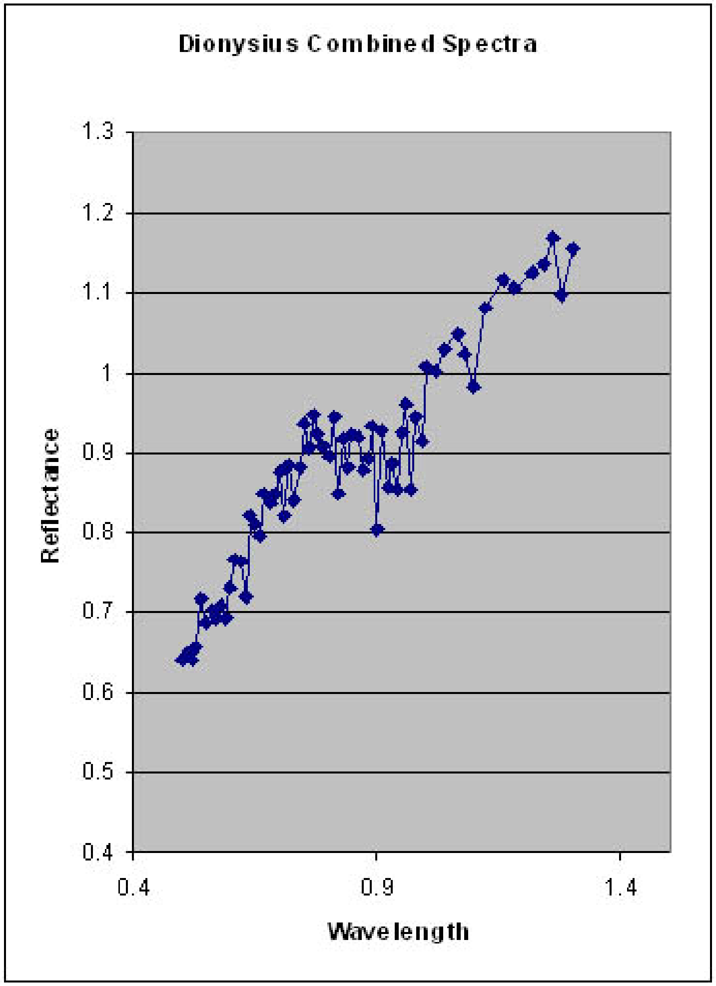
Below is a comparison of the crater Dolland with the Apollo 16 site, with other features labelled for orientation purposes. It appears likely to me that the trough in Dolland's spectrum between about 920 and 950 nm as (compared to the Apollo 16 site) may be due to the presence of at least some low calcium pyroxene, possibly norite or more likely noritic anorthosite, excavated by the crater. Although I began by using the Apollo 16 site for spectral calibration, calibrated spectra of roughly 50 other lunar sites obtained with the Keck telescope are also available on the USGS spectral library site. Since these have already been calibrated against the Apollo 16 site, they can be used in the place of the Apollo 16 site during the calibration process. This makes calibrating spectra much more convenient since it provides roughly 50 additional calibration sites which are widely distributed on the lunar surface.



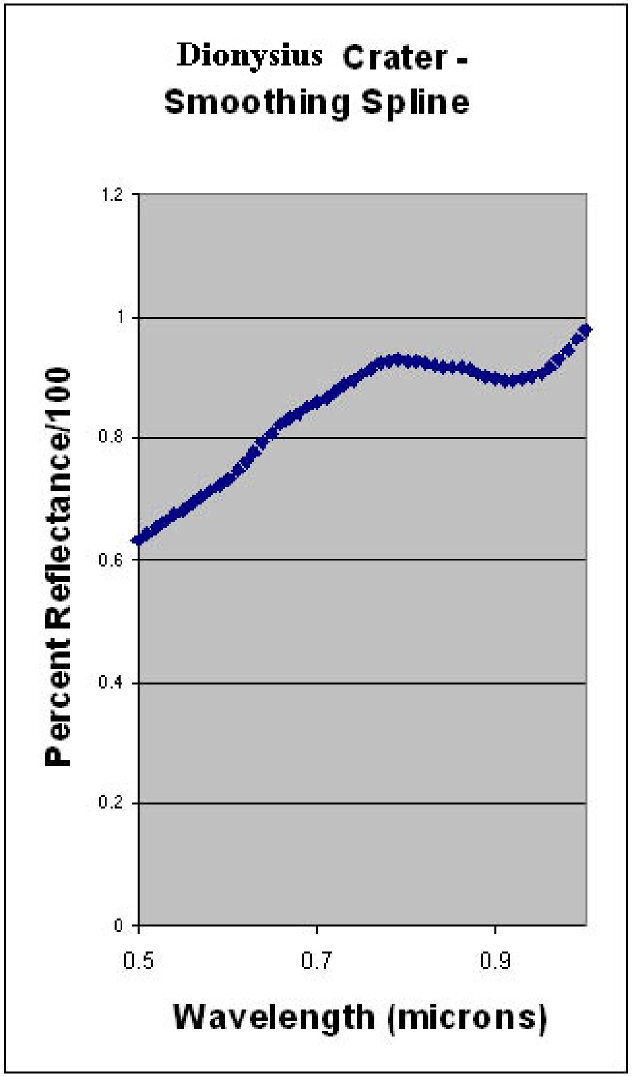
It was also interesting to look at the spectra of Dionysius shows a strong mafic signature with a trough center at about 950 nm. This again suggests either a low calcium pyroxene, possibly norite or noritic anorthosite as the principal mafic component, or perhaps more likely a mixture of pyroxenes.

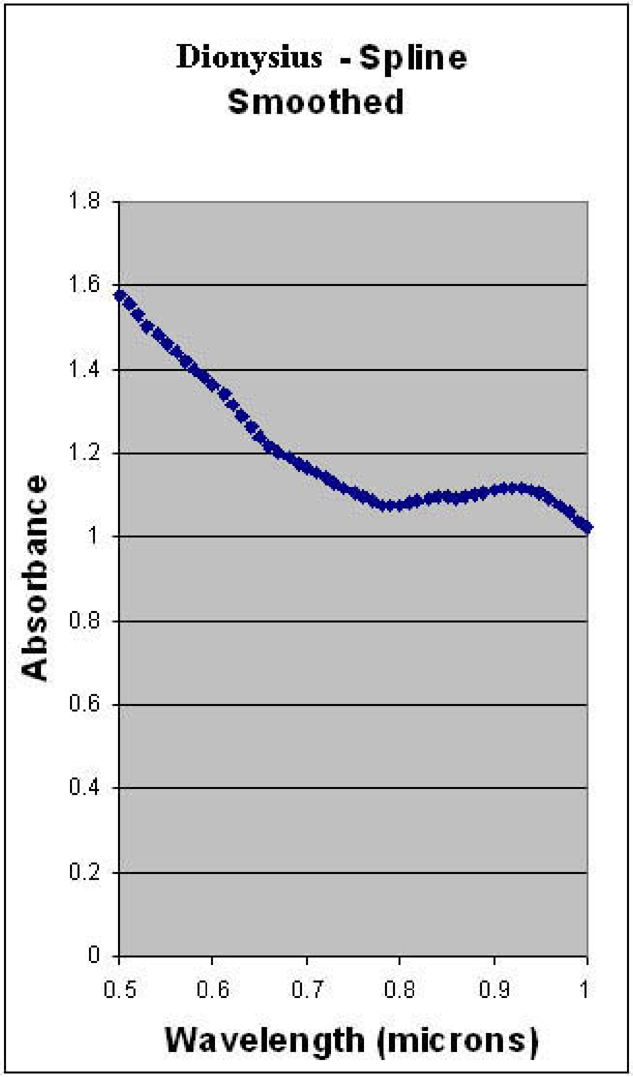


Also, reflectance spectra obtained with cameras having different wavelength coverage can be combined. Because TNTlite will scale the reflectance plots slightly differently for each cameras data, if two data cubes are created (one for each cmera) then a small seam will exist when the data is combined. It is possible to calculate a multiplicative constant using wavelengths common to both cameras which will allow the spectra to be plotted together essentially seamlessly. If the data from the two cameras are combined into a single data cube then no seam will exist and no multiplicative constant will be needed. Similarly, if the spectra for a selected pixel group is calculated manually using ImageJ then there is no need to apply this multiplicative constant as no seam will exist. Combining results with two cameras, a Lumenera075M and an SU320MX, allowed the creation of a spectral plot with a greater wavelength range as shown in the plot below:



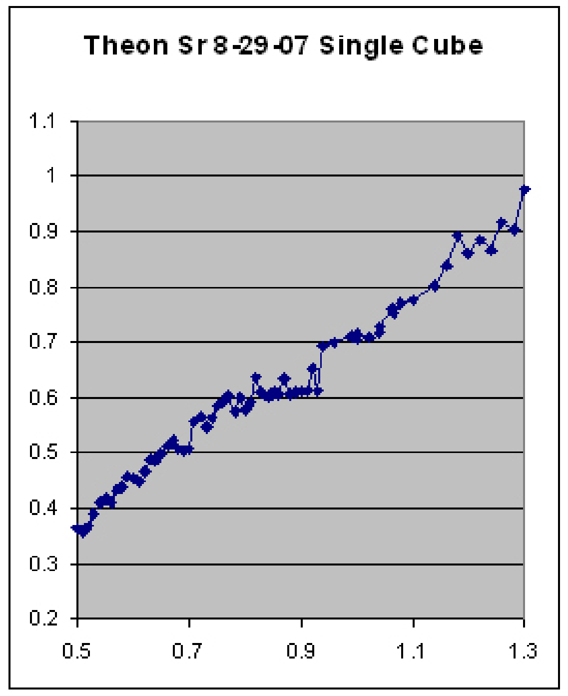
Reflectance and Absorbance plots for Dionysius after application of a Savitzky-Golay smoothing spline are shown below:





Analysis of the absorbance peak between 900 and 1000 nm using PeakFit software shows the peak center to be at about 954 nm.

As discussed bove, it is possible to generate a single hypercube of images from both cameras by co-registering the images with the freeware program LTVT after calibration. The co-registered images can then either be imported into the freeware program TNTmips lite to generate a single image hypercube, or they can be imported into ImageJ as an image stack. In either case, the co-registered images can be used to obtain spectra for the same selected pixel group. With TNTmips lite the process is fully automated whereas with ImageJ the process is manual and requires reading the greyscale values across the wavelength range using the histogram function on the image stack. The relative reflectance plot of the lunar crater Theon Senior below was made from images using 73 individual interference filters on August 30, 2007 at 02:00 UT. A Lumenera 075M camera was used for images between 500 nm and 1064 nm. A Goodrich Sensors Unlimited Su320-MX camera was used to obtain images from 990 nm to 1600 nm. The data was processed into a single hypercube.



Trough parameters for this plot can be calculated after division by a line tangent to the curve through 750 nm and 1250 nm. The resulting band center for the trough is at about 900 nm. The bandwidth is 258 nm and the band depth is 6.7 percent. The area of the trough is 15 nm reflectance units.