EARTH-BASED MULTISPECTRAL OBSERVATIONS OF THE MOON

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Lunar samples returned from the Apollo missions allow us to study the chemical, mineralogical, petrographical and physical state of various lunar soils and rock types. Yet, our understanding of global lunar surface properties is limited: Not all existing surface units are represented in the returned samples. In addition, the global and regional distribution of identified rock and soil types is not known. Much of this information can be obtained from remote sensing data. It is known that spectral reflectance of lunar surface materials is highly indicative for their chemical composition and mineralogy (1,2), whereas photometric measurements at different phase angles are indicative for their physical state (3,4). Unfortunately, in-situ information is only available for the small areas of Apollo landing sites, Apollo x-ray and γ-ray measurements are of low spatial resolution and only small equatorial areas are mapped by these experiments and, so far earth-based high spectral-resolution data exist only for small patches of the surface which reflect the field of view of point source spectrometers. The early Lunar and Apollo Orbiter imaging data provide high spatial resolution but no spectral and photometric information. In fact, most available selenological maps rely on morphology rather than on spectral and photometric surface properties.

Clearly, a new lunar multispectral imaging data base is needed. Two years ago we initiated a program of telescopic lunar observations. During this program we have mapped the lunar nearside in a variety of spectral bandpasses at different viewing geometries. Interpretation of the imaging data is based on the following strategy: Apollo landing sites and the existing spatially unresolved spectrometer measurements of the lunar nearside are used as chemical and spectral references whereas multispectral images of the Moon will provide the required information on areal extent of surface units. Our multispectral data base will also provide important calibration data for the Galileo SSI images taken during the spacecraft's Earth-Moon encounter last december. Galileo images mostly cover the lunar farside, which was almost fully illuminated during the encounter. Illuminated reference areas on the lunar frontside, possibly suited for calibration, are located in the western unsampled hemisphere of Oceanus Procellarum.

Observations and data base: In 1989 an observation run over 5 nights was carried out at the Hawaii Mauna Kea Observatory. The DLR CCD camera with 12 filters on a filterwheel was attached to the 24-inch telescope. The detector used for these observations was a 576x384 pixel TH7882 CCD. Spatial resolution of 2km per pixel on the lunar surface was achieved. The filters have a bandwidth of 20nm and cover the wavelength range from $0.38\mu m$ to $1.0\mu m$. The measurement procedures were computer controlled as far as possible to avoid "human errors" and to increase the efficiency. The goal was to scan as much as possible of the lunar surface in every night. Therefore, we tracked the telescope slightly faster than the motion of the Moon. After the acquisition of data with all 12 filters the telescope has moved one frame further on the Moon, and the next acquistion turn could immediately be started. Using this technique, a coverage of up to 95% of the nearside of the Moon in one night was achieved. Every half an hour additional calibration measurements of the Apollo 16 landing site reference area and of the best-known solar analog star 16 Cyg B were taken. In total the "Mauna Kea data base" includes over 3000 multispectral exposures at about 5 different phase angles between 3° and ~40°

In order to improve the phase angle coverage of selected lunar areas, in 1990 additional observations have been performed in Germany at the University of Munich Wendelstein Observatory using a new 26-inch telescope. This computer controlled telescope allows us to achieve high-precision photometry of the lunar surface. Pictures of the Flamsteed and Apollo 16 area have been taken quasi-simultaneously using the Galileo SSI-filters to obtain a new calibration standard for the SSI data of the Earth/Moon 1 encounter.

The **standard data reduction** of the earth-based multispectral imaging data includes decalibration, extinction correction, registration of spectral channels and calibration against some appropriate lunar spectral standard such as the Apollo landing sites. Besides this standard calibration procedure we applied a photometric correction to the multispectral data in order to eliminate brightness variations induced by different illumination and viewing conditions. The photometric correction is based on the Hapke photometric model (5). Input for this model are the parameters derived from photometric studies of Helfenstein and Veverka (3) for lunar regions of distinct brightness. Thus, a diffential photometric correction for bright highlands, intermediate highlands and dark maria can be performed (2).

Multispectral calibration and analysis: The observed colors are verified by comparing the data with telescopic spectra. For the spectral calibration we used the Apollo 16 landing site. As shown by (6), the laboratory spectra of the Apollo 16 mature highland soil sample 62231 fit very well the telescopic observation. This allows us to transform the multispectral image data after the photometric correction

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into reflectance values. The 12 narrow-band filters together with the 7 SSI filters used in our observations, cover the wavelength range from 0.35 to 1.1 μm at a spectral resolution (Fig. 1), high enough to perform a detailed compositional analysis of the lunar nearside. Spectra of the Apollo 14 landing site and the Mare Humorum 0 reference area (7), obtained with the 12 narrow filters, are shown in Fig. 2. For the study of the lunar surface we applied different image processing methods such as ratioing and HSI-transformation. The spatially resolved reflectance data allows us the quantitative mapping of concentrations for the main chemical constituents by adapting the method developed by (2). This approach transforms the spectral reflectance into chemical abundances by means of a principal component and multiple regression analysis involving laboratory spectra. Spectral-chemical models have been developed for each filter set, respectively. Contents of Fe, Ti, Ca, and Al can be estimated with great confidence. Main emphasis for the spectral evaluation is given to the areas of Flamsteed, Mare Humorum, Tycho, and the western Oceanus Procellarum. These areas have been chosen also with regard to the Galileo SSI camera experiment in order to receive secondary standards for the spectral calibration of the SSI images (8). Based on the transmission properties of the SSI optical system and a multiple regression, the 12 DLR CCD filters can be transformed into SSI reflectances, a method which yields better results than a cubic spline interpolation by a factor of two. Thus, spatially resolved calibration images can be produced. **Photometrical data analysis** : An adequate correction for different viewing geometries is essential for any detailed studies of planetary surfaces. The data base received at Mauna Kea and at Wendelstein offers the possibility of extensive photometric studies with special respect to color-dependent photometric effects on the Moon. The data will also be analyzed using the Hapke model to learn more about the physical properties of lunar soils.

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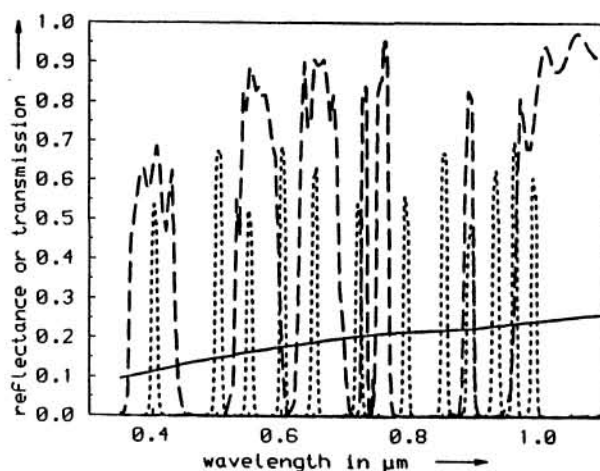(8) *Pieters, C.M. et.al.*, this volume

Figure 1.   Transmission characteristics of the 12 narrow-band filters (dotted line) and the 7 SSI filters (dashed line), together with the laboratory spectra of the Apollo 16 62231 mature highland soil.
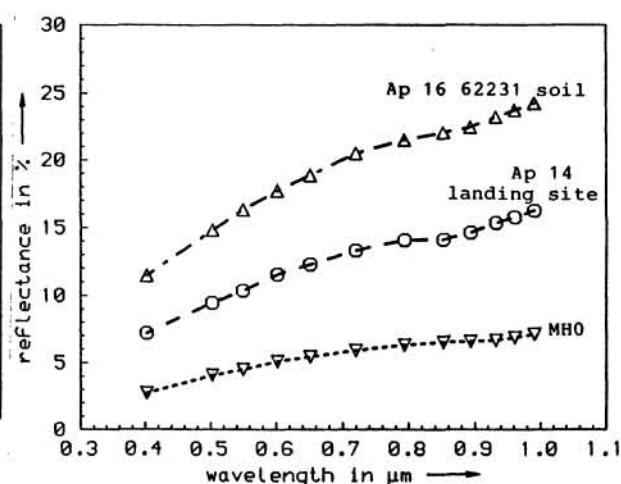
Figure 2.   Photometrically corrected spectra for the Apollo 14 landing site and the Mare Humorum 0 area as observed with the 12 narrow-band filters; top = simulated filter values for the Apollo 16 standard soil.