IMAGING SPECTROSCOPY OF THE MOON IN THE MID-INFRARED: 8.3 TO 13.3 μm IMAGE CUBES OF TYCHO; J.F. Bell III (NASA Ames Research Center, Moffett Field CA), P.G. Lucey, D.T. Blewett, and B.R. Hawke (HIGP/SOEST, University of Hawaii, Honolulu HI), M.S. Robinson (USGS, Flagstaff AZ), T.L. Roush (San Francisco State University, San Francisco, CA), J.D. Bregman (NASA Ames Research Center), D.M. Rank, D. Harker, and P. Temi (University of California, Santa Cruz, CA).

We report our initial progress on the use of a mid-IR array camera and a ≈ 1.5% resolution circular variable filter (CVF) to obtain imaging spectroscopic observations of selected regions of the Moon in the 8 to 14 μm wavelength region. Our specific goals are to detect and spatially map spectral features diagnostic of lunar plagioclase, olivine, pyroxene, and possibly of other rarer silicate phases such as quartz. We have concentrated our efforts on a small number of regions that are well-characterized by other techniques and that have the potential to exhibit high levels of spectral contrast and spatial heterogeneity.

Mid-infrared spectroscopy is a valuable diagnostic tool for the remote identification of minerals on a planetary surface [1-4]. The most prominent features in 8-14 μm spectra are the Christiansen frequency (CF), which is an emissivity maximum corresponding to the wavelength at which the index of refraction of a material and its surroundings are equal, and the Restrahlen bands (RB), which are the fundamental stretching modes of Si–O bonds.

For the Moon, mid-infrared spectra provide important information on silicate minerals that cannot be uniquely identified at shorter wavelengths. The major questions in lunar science that can be addressed by mid-IR observations are: (1) What is the abundance and distribution of anorthite and anorthositic rocks? Because plagioclase feldspars such as anorthite typically do not contain much iron, VIS-NIR spectroscopy is unable to uniquely detect or map most lunar anorthites. The positions of certain spectral features from 5 to 15 μm can be sensitive indicators of plagioclase composition [5]. In turn, knowledge of the plagioclase compositions on the Moon would constrain formation models for the lunar crust (*e.g.*, differentiation and/or formation of a "magma ocean" [6]), and determination of the spatial variability of these materials could help constrain models of the subsequent physical and chemical evolution of crustal materials. (2) What is the chemical composition of lunar olivines? Mid-IR spectroscopy, unlike VIS-NIR techniques, is sensitive to the magnesium *and* iron content of olivines [*e.g.*, 7]. (3) What other iron-free minerals exist in detectable abundances on the Moon? Again, the mid-IR offers particular advantages over the VIS-NIR for the detection of rare materials such as quartz and alkali feldspars [4, 8, 9].

Mid-infrared remote sensing observations of the Moon since the 1960s have been reviewed by [4, 10, 11]. To summarize, seven major observing efforts have been conducted using a variety of groundbased and balloon-borne spectrometers in the 7 to 13.5 μm region. These observations have revealed detectable spectral heterogeneity in the mid-IR associated with variations in RB structure and CF emission maxima that imply diagnostic variations in surface composition. The spatial resolution of these previous measurements ranged from 5 to 300 km per spot, and the spatial coverage is only for a very small fraction of the nearside. No 8-14 μm imaging observations of the Moon have been reported in the literature besides the broadband (8-10.5 μm) Clementine imaging data, and only recently were the first 5-7 μm observations reported [12].

Our data were obtained with a camera based on an Amber Engineering 128×128 Si:Ga array mounted in a standard LHe dewar [13]. This is the same camera that was used with a different CVF for the 1993 KAO Moon observations reported in [12]. The camera was mounted on the U.C. Lick Observatory 40-inch Nickel reflector. Images of the Tycho and Copernicus regions were obtained on 1994 June 20 and 21 UT in 89 wavlengths from 8.3 to 13.3 μm. Along with Moon images, sets of flatfield, dark current, linearity test, and near-lunar sky images were obtained. These images and standard "CCD-like" data reduction procedures were used to convert the raw data into instrumental DN units that should be within a simple scaling of absolute flux units. Unfortunately, because of time constraints and the exploratory nature of these observations, standard stars were not observed and so the images cannot be calibrated to an absolute scale. However, relative differences between spectra are accurately represented in these data, and we estimate that the instrumental signal-to-noise of the data averages from 0.17% to 0.35%. After performing dark removal, flatfielding, and sky subtraction on the data, the images were stacked into an image cube (128×128×89). Automatic tiepoint selection for spatial registration of the cube was achieved by dividing each wavelength band into 20×20 pixel tiles and performing an autocorrelation between each tile and a corresponding tile in one band chosen as the reference. This resulted in 20-30 control points per image, at 0.2 pixel precision. Then, a weighted transformation was applied through the cube so that the tie points were held essentially fixed and regions between tie points were stretched to remove complex distortions and small changes in scale. Wavelength calibration (±0.05 μm) was achieved by measurements of polystyrene lines. Wavelength refinements and a correction for wavelength variations across the chip were achieved by observing the telluric O_3 band near 9.6 μm and applying the same registration routine described above to the wavelength data.

An example of the data quality is shown in Fig. 1, which is an image of Tycho at 11.96 μm. The field of view ranges from -36° to -52° latitude and 3° to 19° longitude (≈ 350×500 km). The Tycho central peak is resolved, as are large regions of the floor and walls of Tycho and of many surrounding craters. Fig. 2 shows ratio spectra of some representative units in the cube relative to the Tycho floor spectrum. The ratio spectra show substantial spectral structure, some of which appears to be related to variations in plagioclase (either albite or anorthite) in this highlands-dominated region. Additional analyses will concentrate on quantifying the nature of these spectral differences using traditional single-spectrum techniques as well as image-oriented techniques like color ratios, band depth maps, spectral mixing, and PCA.

Fig. 1: Brightness image at 11.96 μm of our Tycho image cube region. North is up. Tycho (center) is 85 km in diameter, central peak is 12 km diameter. Data obtained in 89 wavelengths from 8.33 to 13.35 μm on 1994 20 June 0530UT using the Lick Observatory 40-inch telescope at Mt. Hamilton, CA.

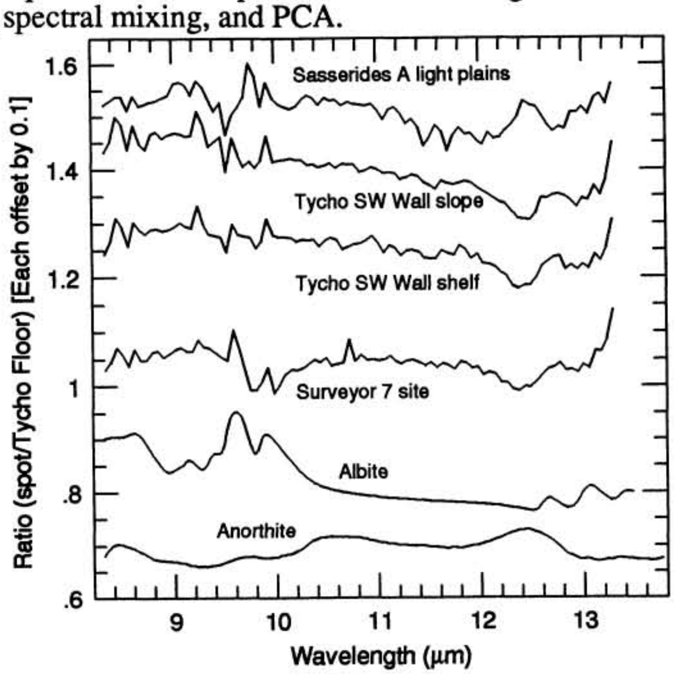

Fig. 2: Ratio spectra of four regions relative to a spectrum of the floor of Tycho. Shown for comparison are reflectance spectra of albite and anorthite from [3], on different scales.

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