

WATER ON THE MOON? POTENTIAL DETECTION OF RECENT COMETARY IMPACTS IN THE EARTH/MOON ENVIRONMENT USING LGO/VIMS Carle M. Pieters, Peter M. Hill, Kari P. Magee, and Jessica M. Sunshine, Brown University, Providence RI 02912

Most discussions of searching for water on the Moon have focused on the small permanently shadowed areas near the poles where, protected from solar radiation, water might accumulate and survive the harsh environment of the lunar surface (1). The existence of such deposits of water could be detected using a polar-orbiting gamma-ray spectrometer which detects diagnostic gamma ray emissions of surface water resulting from stimulation by galactic cosmic rays (2) at relatively low spatial resolution. Although water and OH also exhibit characteristic absorptions in the near-infrared (near 2.8 μm) due to their fundamental stretching modes of vibration, the higher spatial resolution reflectance spectroscopy instruments cannot be used to explore the permanently shadowed areas because detection of these absorption features of course requires solar illumination. Near-IR absorption features of water are nevertheless very strong and can be used to detect water at a fraction of a weight percent (3). The use of reflectance spectroscopy for detection of water on the Moon is reexamined here in the context of recent cometary impacts, and the planetary science community is urged to help resolve remaining unknowns (several underlined in text). The Visual and Infrared Mapping Spectrometer (VIMS) being developed for Mars Observer is designed to operate efficiently near these water absorption bands and the sister Lunar Geoscience Observer/VIMS would have similar characteristics. Typical specifications for LGO/VIMS would be an instrument that measures radiation from 0.3 to 4.3 μm (with $\sim 10\text{nm}$ spectral resolution to 2 μm and $\sim 19\text{nm}$ beyond) with a pixel (picture element) resolution of 0.33 km on the surface.

Interaction of a Comet with the Moon. Since the returned lunar samples show the Moon is essentially devoid of water, any water or hydrated minerals detected at unsampled areas with remote sensors, including volatiles trapped in the polar shadows, must have come from external sources, such as impact(s) from volatile-rich comet(s). A cometary impact on the Moon may also leave a local signature in the form of rapidly created hydrated minerals or quenched water inclusions as cometary volatiles interact with desiccated lunar silicates during the impact explosion. Although rates of formation have not been experimentally determined for the lunar conditions, a wide range of (temporary) atmospheric pressure and temperatures may occur in the near and far environment around a cometary impact. Once formed, the rates of destruction of hydrated material are also not well known, but exposure ages for volatile rich meteorites such as CI and CM (inserted by definition into the earth/moon environment) suggest hydrated minerals can last several million years (4) in/near this space environment. For the purposes of this discussion, we hypothesize that interactions of a comet with the Moon will produce hydrated silicates in surface material associated with the interaction (e.g. crater ejecta, impact melt, rays, or swirls) that will remain in the local region a finite period of time. With the high precision and high spatial and spectral resolution of LGO/VIMS, the strong 2.8 μm absorption feature of water should allow its detection, if present, at localized areas.

Measurement Difficulties. Although LGO/VIMS will have direct solar calibration, accurate spectral reflectance measurements at wavelengths beyond $\sim 2.2 \mu\text{m}$ will be difficult because an increasing amount of lunar thermal emission is included with the reflected solar radiation in each VIMS measurement. Although peak lunar emittance occurs well into the infrared near 10 μm , the thermal component can be 20 - 50% of the total flux at 3 μm . In order to determine the reflectance spectrum around the 2.8 μm water absorption feature, the contribution of lunar thermal flux must be well defined at each wavelength for each pixel. With the projected capabilities of VIMS/LGO, we do not feel these problems are insurmountable and provide an assessment and possible solution to this technical difficulty below.

Reflected/Thermal Radiation from the Moon. The spectral reflectance and emissivity properties of lunar materials have not been measured in the laboratory or with remote sensors for the part of the spectrum necessary for this experiment (2.0 - 4.5 μm). These properties are not easy to obtain in the laboratory because of the ubiquitous presence of terrestrial water. To assess the nature and magnitude of the problem, reflected and thermal flux estimations have been calculated using extrapolations from available data and several assumptions. Salisbury (5) has shown that for particulate surfaces, reflectance (and emittance) at wavelengths shorter than 6 μm is dominated entirely by volume scattering and that minerals common to the Moon show no major absorptions (other than water) from 2.5-5 μm . Lunar reflected flux (reflectance x incident solar flux) was calculated using a 6000° black body solar flux estimate with a latitude correction. Reflectance values to 4.3 μm for mature highland and mare soils were estimated as a straight line extension of soil spectra obtained to 2.5 μm (J.B. Adams' collection). Emitted flux was calculated as black body emission using temperatures measured (at 10 μm) for typical surfaces at each lunar latitude (6) times the emittance as a function of wavelength. Spectral emittance values were approximated for highlands and mare using Kirchoff's law ($E=1-R$). Lunar temperatures range from 398 to 350°K for 0° to 80° latitude at minimum phase angle. Expected flux values from the lunar surface are shown to range over almost three orders of magnitude. The proportion of thermal component is not constant but varies with both surface type (albedo) and latitude. Typical flux values are shown in Figure 1. For the low albedo mare, thermal flux averages about 30% of the total at 2.8 μm

and reaches almost 90% at 4 μm . For highland soils, the proportion at 2.8 μm is 10-15% and 70-80% at 4 μm . The crossover point of equal reflected and emitted flux is near 3 μm for most mare soils and ranges from 3.15 to 3.5 μm for highland soils, with the shorter crossover at higher latitudes. These calculations of thermal flux contributions show the range expected for LGO/VIMS, but their distinct variations underline the importance of direct thermal flux measurement of each surface pixel in order to examine spectral reflectance properties near 2.8 μm .

Isolating Spectral Reflectance near 2.8 μm . Since LGO/VIMS will have solar calibration capabilities, spectral reflectance $[R(\lambda)]$ can be easily obtained for wavelengths containing insignificant thermal component. At these wavelengths, the measured flux $[MF(\lambda)]$ is the product of the incident solar flux $[S(\lambda)]$ times the spectral reflectance of the surface $[R(\lambda)]$. The solar flux is measured directly by VIMS and converted to absolute flux using preflight calibrations. At wavelengths beyond $\sim 2.2 \mu\text{m}$, however, the measured flux contains both the reflected and emitted radiation from the surface. The emitted radiation is the product of black body emission $[B(\lambda, T)]$ of the surface (a function of temperature) times the spectral emissivity $[E(\lambda)]$. If Kirchoff's law holds for the relation between reflectance and emissivity $[R(\lambda)=1-E(\lambda)]$, the measured flux can be expressed as $MF(\lambda) = R(\lambda) [S(\lambda) - B(\lambda, T)] + B(\lambda, T)$, where both $MF(\lambda)$ and $S(\lambda)$ are measured directly, $R(\lambda)$ is the desired unknown, and $B(\lambda, T)$ is a function of temperature only. Thus if the temperature of the surface can be determined for each surface measurement, $B(\lambda, T)$ can be calculated and reflectance values obtained throughout the spectrum. Although LGO/VIMS obtains data to 4.3 μm , the flux at this wavelength is only 70-90% emission and cannot be directly used to calculate the surface temperature. Our proposed solution is to use the reflectance values measured accurately at shorter wavelengths (0.3 to 2.2 μm) to estimate the reflectance at 4 μm (by comparisons with independent laboratory measurements of lunar materials). With a good estimate of the reflectance $[R(\lambda)]$ for wavelengths near 4 μm , $B(\lambda, T)$ and hence the temperature can be obtained from the above equation for each pixel. With these approximations, continuous spectra can be obtained across the 2.8 μm water absorption band, except for the small range of wavelengths beyond 3 μm when $R(\lambda)$ is indeterminate $[S(\lambda) = B(\lambda, T)]$.

Applications. If this aspect of the LGO/VIMS experiment is successful, there are at least two significant applications for the direct detection of water on the Moon associated with recent cometary impacts: (1) Since LGO will provide global coverage, the cometary flux for the terrestrial environment in the recent past can be determined from the better preserved statistics of lunar cometary impacts. Such independent flux information is fundamental to evaluating the effects of impact events on the recent geological (and biological) evolution on Earth. (2) If hydrated material is found to be relatively abundant at any location on the Moon, it of course provides an extremely valuable natural resource for long-term lunar exploration/utilization.

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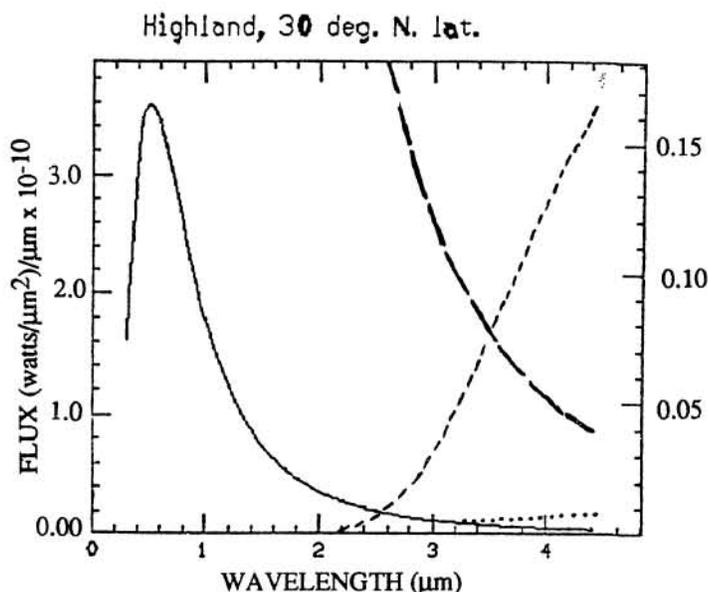


Figure 1. Reflected and emitted flux for a lunar highland soil at 30° Lat.

Left scale:

(solid curve) reflected solar flux
(dotted curve) reflected + emitted flux.

Right scale:

(long dashed curve) reflected solar flux
(short dashed curve) emitted flux.