GROUND BASED OBSERVATIONS OF LUNAR WATER: CURRENT STATUS . A. S. Rivkin[1], J. M. Sunshine[2], D. T. Blewett[1], B. A. Cohen[3], D. M. Hurley[1], J. A. Grier[4] C. A. Hibbitts[1], and R. L. Klima[1], [1]JHU/APL, [2]U. Maryland [3],NASA MSFC, [4]PSI

Background: While the presence of ice was suspected at the lunar poles long before its confirmation, the lunar regolith at lower latitudes and in sunlit areas has long been characterized as dry. However, spurred by the possibility of solar wind-created water in the regolith, spectral studies have been done both from the ground [1] and from space. Three spacecraft in particular (each with differing strengths and limitations) have recently released results centering on lunar water. M^3 on the Indian Chandryaan-1 spacecraft [2] had high spatial resolution (70 m/pixel) but wavelength coverage that ended at 3.0 µm, too short for effective thermal flux corrections of warmer targets. VIMS on Cassini has good wavelength coverage, but very low spatial resolution during an Earth gravity assist: 175 km/pixel for its lunar observations [3] Deep Impact (DI) has been able to observe the Moon on three occasions [4] and has been able to provide some limited temporal coverage with good wavelength coverage, but its spatial resolution is 10 km/pixel in limited areas with generally lower spatial resolution.

However, data from all three of these spacecraft agree that the Moon has a 3-µm band, interpreted as a water and/or OH feature, widespread across its surface. The M^3 data, largely restricted to higher latitudes due to the thermal flux removal issues, shows some compositional differenes (stronger bands in anorthosites) and higher band depths are associated with "fresher" craters. The Deep Impact data show shallower band depths near local noon, with greater band depths in early morning and late afternoon. While both highland and mare regions always have the band to some degree, the variation in the maria was seen to be greater than in the highlands. This is most easily explained as changes with local temperature, though Clark (2009 in Supporting Online Material) argued that photometric effects complicate the situation.

The independent observation of 3-µm bands on the Moon by these three spacecraft, was very surprising given the previously described understanding of the lunar surface as extremely dry. While interpretations are continuing to evolve, the early consensus seems to be that the band is due, at least in part, to adsorbed water and OH likely created by the interaction of solar wind protons with silicates in the lunar regolith.

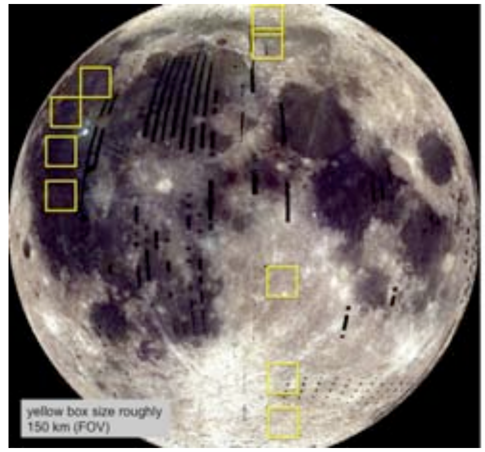

Figure 1: Nine lunar locations have been observed so far, with an emphasis on a highlands latitude traverse and a near-limb traverse in Oceanus Procellarum.

We have undertaken a three-year program to follow up the spacecraft results through observations of the Moon and near-Earth asteroids in the 3-µm spectral region, funded by the NSF. We will present some preliminary findings from our initial observing run in September 2010. To begin we have focused on the Reiner Gamma (RG) Formation, the classic lunar swirl. RG sits in relatively flat area in Oceanus Procellarum, with a presumably homogeneous composition. A current hypothesis for lunar swirl formation centers on protection of the surface from solar wind interactions via magnetic shielding [e.g., 5, and references therein]. Variation in 3-µm band depth at RG and other swirsls was seen in M^3 data, consistent with this hypothesis [6].

Observations and Reduction: We used the NSFCam2 instrument on the NASA Infrared Telescope Facility (IRTF) on UT date 21 September 2010, observing nine different locations on the lunar surface (Figure 1). The Moon was in waxing gibbous phase, and target areas were located at a variety of latitudes and viewing angles. NSFCam is a 1-5 µm array, and we used the circular variable filter (CVF) to image at 11 wavelengths from 2.3-4.0 µm. In addition to the lunar targets, the solar type star HD 223238 was observed in order to allow removal of solar flux and accurate ties from one wavelength to another. The weather was excellent, with precipitable water of roughly 2 mm and sub-arcsecond seeing (translating into a seeing-controlled spatial resolution better than 2 km).

Full data reduction includes flat-field correction, photometric correction, thermal flux removal, and solar color removal.

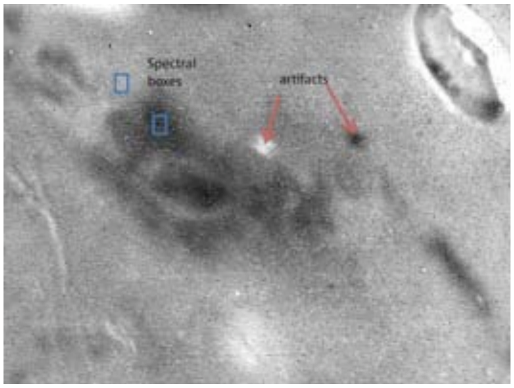

Figure 2: 4.0 µm/2.4 µm ratio image of the Reiner Gamma (RG) region. North is down, east to the right, with Reiner crater (29-km diameter) in the upper right of the image. This image emphasizes the difference in thermal flux between RG and the background (BG), due to RG's higher visible albedo and thus lower temperature. Artifacts are also visible, such as the bright spot just above the center of the image and its dark spot complement to its right, both marked with red arrows. Areas used in the spectra shown in Figure 3 are boxed.

Results: At this writing, reduction is ongoing. However, we can already detect some differences between RG and the background (BG). Figure 2 shows the 4.0 µm/2.4 µm flux ratio for RG, and it is clear that the contrast for RG switches at long wavelengths. The flux ratio is consistent with models of thermal flux from a higher-albedo and lower-temperature RG (albedo ~0.12) vs. a lower-albedo and higher-temperature background (albedo ~0.08) at the observed local solar time.

Figure 3 shows *very premlinary* spectra for a location in RG and a nearby location in the BG. Error analysis is incomplete but error bars are estimated to be ~5-10%, though we expect uncertainties to decrease with more rigorous analysis. The comparison of RG to BG spectra is consistent with a flat line within the current uncertainties, but also is consistent with a feature at 2.73 µm of a few percent. Such a feature would most likely be due to OH.

Discussion: The task of obtaining the data critical to understanding the state, distribution, and evolution of lunar water falls to groundbased telescopes. Cassini and DI will not be returning to the Moon, and Chandryaan-1 ceased operations over a year ago. The Lunar Reconnaissance Orbiter (LRO), currently orbiting the Moon, has no instruments capable of making observations at these wavelengths. Only DI had any time coverage, with two observations a week apart. While the Earth's atmosphere generally precludes observations between 2.55-2.85 µm, the absorptions seen on the Moon are broad enough to be detected from Mauna Kea. Specific lunar targets can be observed multiple times by groundbased facilities at different lunar local times with higher resolution than was available for DI and Cassini, and expanded wavelength coverage compared to M^3.

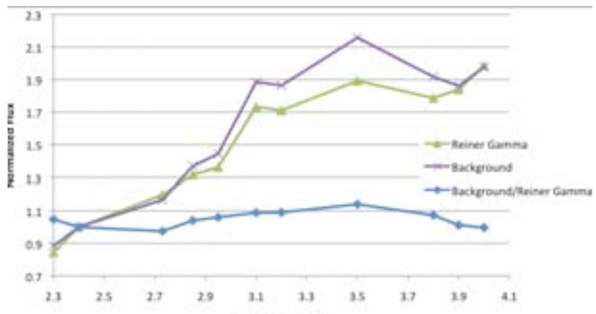

Figure 3: The spectral properties of a spot within RG and a background spot to its southwest (BG). Preliminary thermal and photometric corrections have been applied to these data, with the resulting ratio also shown. Error bars are omitted, but are estimated at roughly 5-10% at this point. Neglecting error bars suggests the background has a 2.7-µm band, presumably due to OH, of ~10% relative to RG. However, when taking the current uncertainties into account, the ratio is also consistent with a flat line. Further work will improve the calibration and reduce the uncertainties.

Our observations will provide data that are not constrained by flyby geometry or other mission constraints. The ability to observe regions of our choice also guarantees high-science priority areas as well as standard regions can be covered as well as necessary. One additional benefit our observations will provide the community is observations of multiple sites at different times of the lunar day. This will test the finding that the absorption bands shrink and grow with varying solar elevation/time/temperature. While earthbased observations are limited in viewing geometry, they provide invaluable complementary information and opportunities to spacecraft datasets.

References: [1] Roush T. L. and Lucey P. G. (1987) *LPS XVIII* 397. [2] Pieters C. M. et al. (2009) *Science, 326*, 568. [3] Clark R.N. (2009) *Science, 326*, 562. [4] Sunshine J. M. et al. (2009) *Science, 326*, 565. [5] Blewett. D. T. et al. (2011) *JGR* in press. [6] Pieters C. et al. *DPS 42*, abst. #18.01

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