REGIONAL MAP OF WATER AT HIGH SOUTHERN LUNAR LATITUDES USING 6 µm DATA FROM THE STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY. C. I. Honniball[1], P. G. Lucey[2], A. Arredondo[3], W. T. Reach[3], and E. R. Malaret[4], [1]NASA Goddard Space Flight Center, Greenbelt, MD, USA. (casey.i.honniball@nasa.gov). [2]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, Honolulu, HI, USA. [3] Universities Space Research Association, Columbia, MD, USA. [4]Applied Coherent Technology, Herndon, VA, USA.

Introduction: Of all the lunar volatiles, water is of high interest due its use as a resource for space exploration. But before water can be used, we must understand its sources, retention, abundance, and behavior on the lunar surface. This can be accomplished with *in-situ* measurements such as those planned by NASA's Volatiles Investigating Polar Exploration Rover (VIPER) and by remote sensing observations.

Using the Stratospheric Observatory For Infrared Astronomy (SOFIA) the first direct detection of molecular water on the sunlit surface was made [1]. Here we present follow up observations with SOFIA that confirm the presence of water at 6 µm, and produced regional maps of water that begin to test various hypotheses for water formation and variation. We explore whether latitude or temperature is controlling the distribution of water.

SOFIA Observations: Spectral data were obtained on June 23rd, 2021 with the Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST) [2]. We used the FORCAST G063 grism with a 2.4 by 191 arcsecond slit to obtain spectra from 5 to 8 µm with a spectral resolution of about 12 nm. The spatial resolution of each pixel at the lunar center of disk is about 4.8 x 1.5 km.

A region surrounding the southern polar crater Moretus (70.6˚S, 6.4˚W) was chosen for measurement as it is known to have high values of "total water" ($OH+H_2O$) based on measurements using the Moon Mineralogy Mapper on the Chandrayaan-1 lunar orbiter [3]. A near equatorial portion of Mare Fecunditatis was chosen as a dry reference location due to the higher temperatures than the Moretus region.

Calibration and processing of the data follows the methodology of [1] with a few improvements to the atmospheric removal and corrections to residual artifacts [4].

Results: All spectra of the region surrounding Moretus crater relative to the mare reference site exhibit an emission feature near 6 µm. The centers and widths of the bands are consistent with water bearing crystalline hydrates [5], hydrated meteorites [6], a sample of water bearing glass [7,8] and the data collected of the Clavius region [1]. Temperatures derived from the radiance spectra are consistent with expectations for this latitude and lunar time of day based on time of day bolometric temperature measurements derived from the LRO Diviner Lunar Radiometer [9]. Water concentrations range from 100 to 400 ppm, consistent with those reported by [1] for the nearby Clavius region.

Figure 1a shows an orthographic projection of the mean flux at 5 to 8 µm. Craters and other topographic features are readily apparent and the radiance is dominated by thermal emission. Temperature is largely controlled by the effect of local slopes dictated by the angle of the surface normal to the Sun, resulting in images that appear very similar to visible images of the

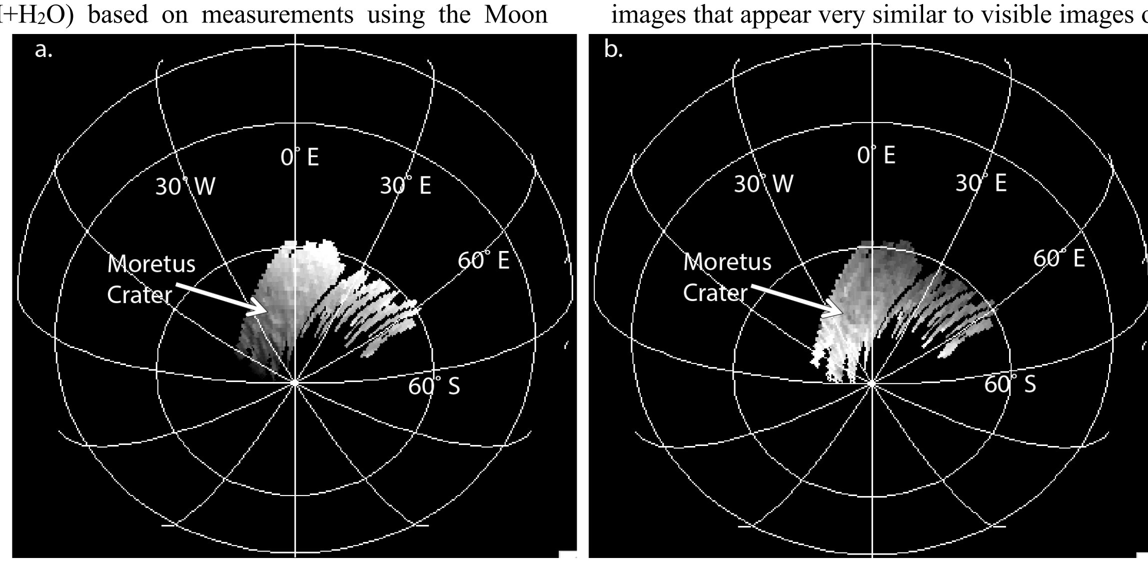

Figure 1: Orthographically rectified images of average flux (a) and emission peak height (b).

Moon obtained at moderate and large phase angles. The images feature a roughly north-south gradient in flux consistent with the orientation the subsolar point (0.6˚ N, 21.25˚ E) that was north and slightly to the east of Moretus longitude, and modulation by temperature variations due to local slopes. An image of the emission peak height is shown in Figure 1b. There is a moderate inverse correlation of peak height and flux which indicates a control by temperature or latitude.

Discussion: These new measurements confirm the findings of [1] that the lunar south polar region features ~200 ppm molecular water relative to a low latitude mare site based on observations of a 6 µm surface emission feature.

Similar to [1] we conclude that the water sensed by SOFIA+FORCAST cannot be that of migrating water [4]. Instead the water is either trapped within silicate impact glass or a mineral-based host. Water trapped in glass is supported by impact experiments [10] and water synthesis experiments [11] and does not invoke speculative chemical reactions.

Our results have implications for models or hypotheses for water distribution. Models that correlates water with solar wind fluence are inconsistent with our observations. For example, if hydroxyl were correlated with fluence, then presumably micrometeorite impact would convert a portion of this hydroxyl to water, a portion of which could in turn be sequestered in impact glass. The ratio of solar wind fluence between our reference and the Moretus site is between 5 and 15 using the equations and assumptions of [12], whereas our estimated water abundance is ~200 ppm higher at the southern Moretus site. This is the reverse of expectation if solar wind fluence dominated water concentrations.

Our data are consistent with a model of [14] where hydroxyl is eroded from low latitudes through recombinant desorption of surface correlated hydroxyl to water and hydrogen released into the exosphere, facilitated by high equatorial midday temperatures. For this model to be consistent with our data, we must assume that water is formed per [11] from pre-existing hydroxyl and trapped in impact glass, and so follows the evolved hydroxyl distribution.

Owing to the high correlation of latitude and temperature in our data, we do not constrain models that require water to respond to the instantaneous temperature, though ballistic migration appears inconsistent with the exospheric limits imposed by NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) and the surface abundance we measure.

The observations of [1] and those presented here are both relative to a mare reference. In the case of [1] the reference was colder than the Clavius region while the reference used for the Moretus region was warmer. In both cases the abundance of water reported range from 100 to 400 ppm irrespective of the reference used. This indicates that the references, both cold and warm had little water present. This potentially indicates the controlling factor for the presence of water on the Moon is latitude with low latitudes having little water and high latitudes having more water.

Conclusion: We have verified the observation that excess water is found at high lunar latitudes. We have strengthened the correlation of temperature or latitude with water abundance. This set of data cannot distinguish which parameter dominates but in combination with observations of [1] may be suggesting latitude is the controlling factor. A simple model suggests that ballistic migration of water through the exosphere is not consistent with most of the detected water being exchangeable with the exosphere, though does not rule out a small amount.

Models that result in hydroxyl abundances correlated with solar wind fluence seem ruled out, but this assumes micrometeorites will trap water in impact glass and freeze in a distribution similar to hydroxyl. A hybrid of the [13] model that results in strong latitude increases in hydroxyl toward the poles, and trapping of water synthesized from hydroxyl into impact glass is consistent with our data.

Further observations can create robust tests of these models. The variation of water with time of day at any latitude constrains the ballistic migration hypothesis, and any other model that forms water proportional to instantaneous temperature, so time of day observations are critical, including at low latitudes since 3 µm observations suggest that hydration increases toward the terminator.

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