
Supplementary information

**Molecular water detected on the sunlit
Moon by SOFIA**

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Supplementary Material

Molecular Water Detected on the Sunlit Moon by SOFIA

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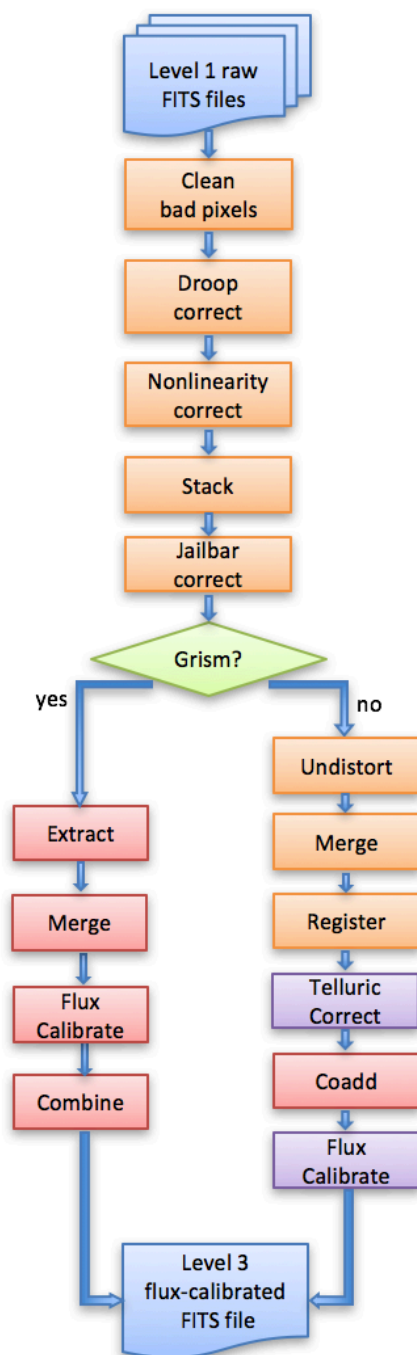
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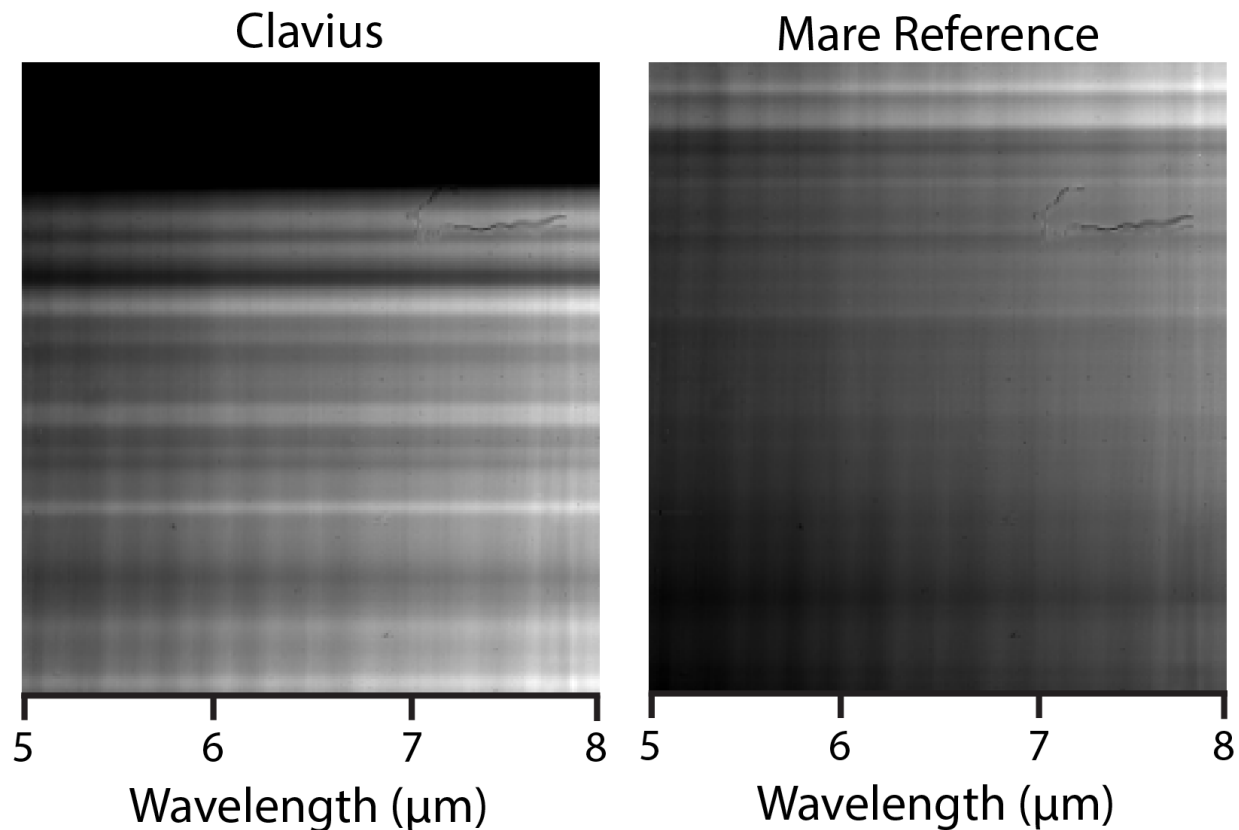
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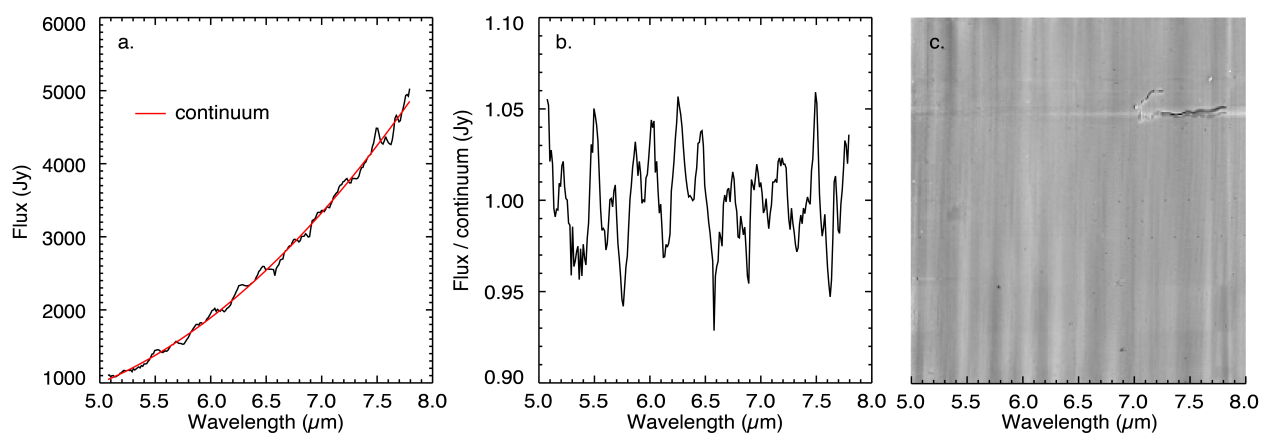
Figures



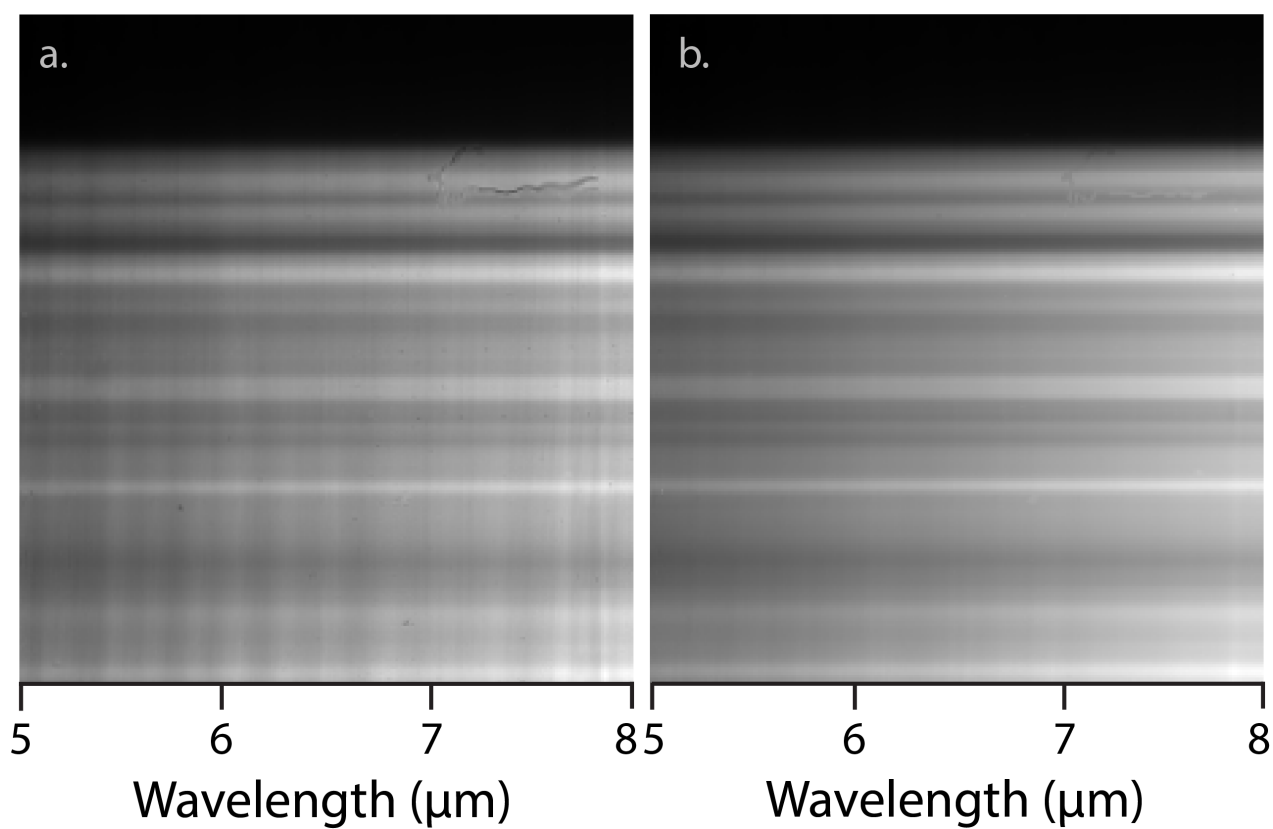
Supplementary Figure 1: SOFIA processing pipeline. Processing steps for FORCAST data. [SOFIA Guest Observer Handbook for FORCAST Data Products]



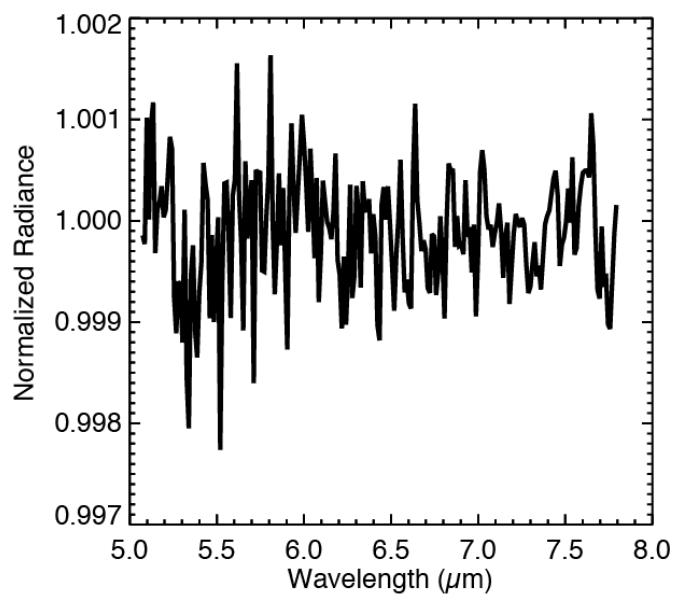
Supplementary Figure 2: Uncorrected frames. Spectral images from SOFIA of the Clavius and mare reference regions and their surrounding area. Oscillation superimposed on this image is not a lunar feature. The artifact on the top right is due to some contamination on the window of FORCAST.



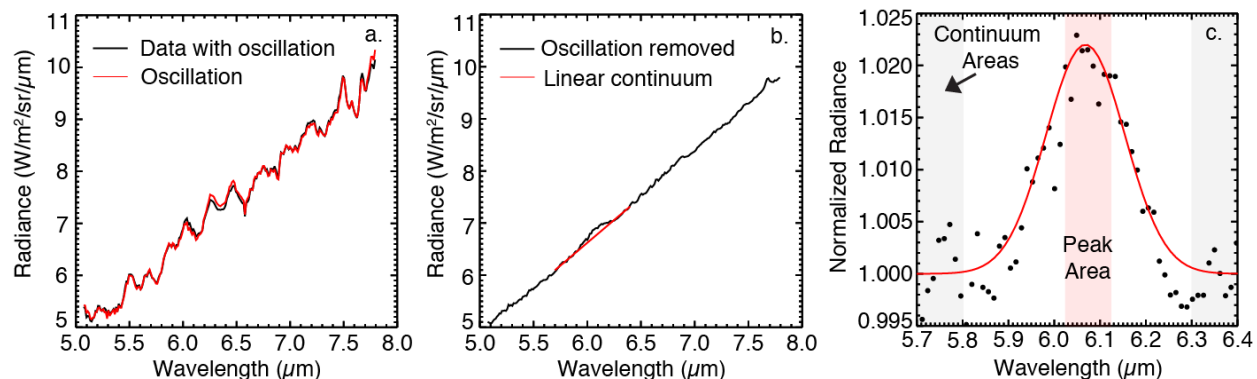
Supplementary Figure 3: Isolating oscillation. a.) Flux spectrum from a mare reference image showing the oscillation and continuum to be removed in red. b.) continuum removed spectrum. c.) Mare reference oscillation image.



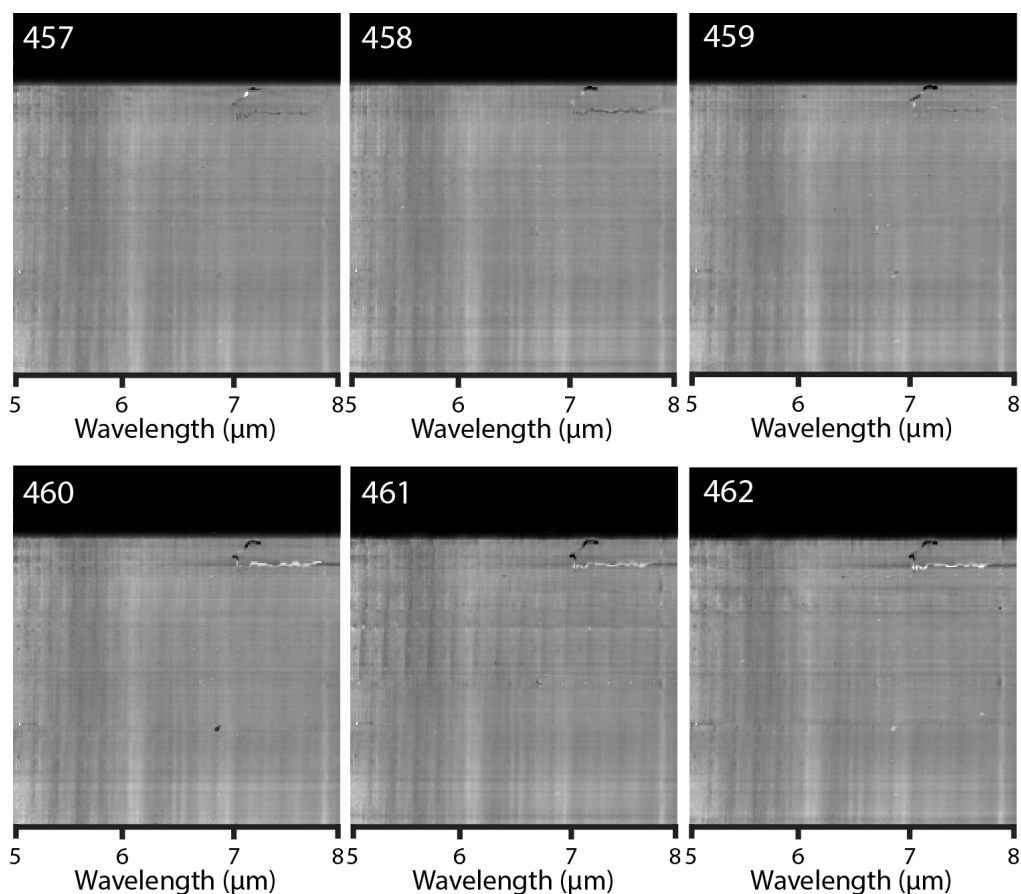
Supplementary Figure 4: Uncorrected vs corrected oscillation. a.) Spectral images from SOFIA of the Clavius region and surrounding area. Oscillation superimposed on this image is not a lunar feature. The artifact on the top right is a defect on the FORCAST focal plane. b.) Oscillation removed spectral image of the Clavius region.



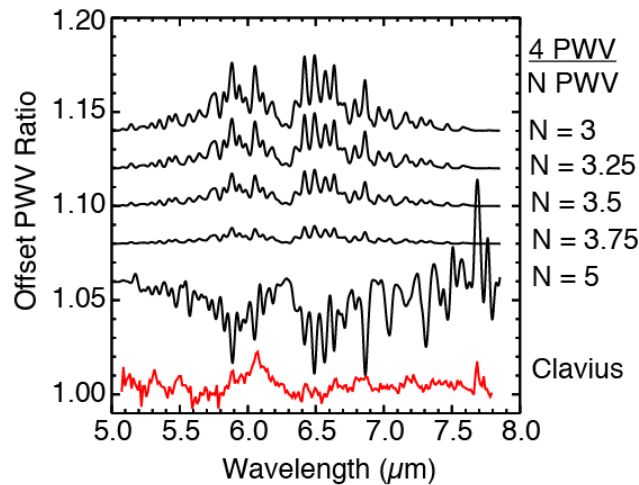
Supplementary Figure 5: Reference spectrum. Spectrum from the mare reference that has the oscillation and a 4th order polynomial continuum removed.



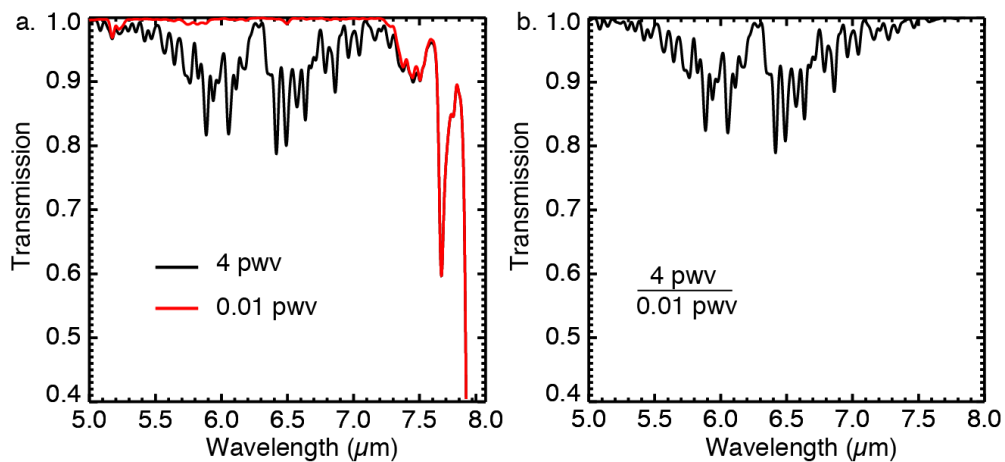
Supplementary Figure 6: Step-by-step processing. Clavius spectrum at 55.7°S and 16.0°W a.) with oscillation, b.) with oscillation removed, and c.) with the oscillation and a linear continuum removed.



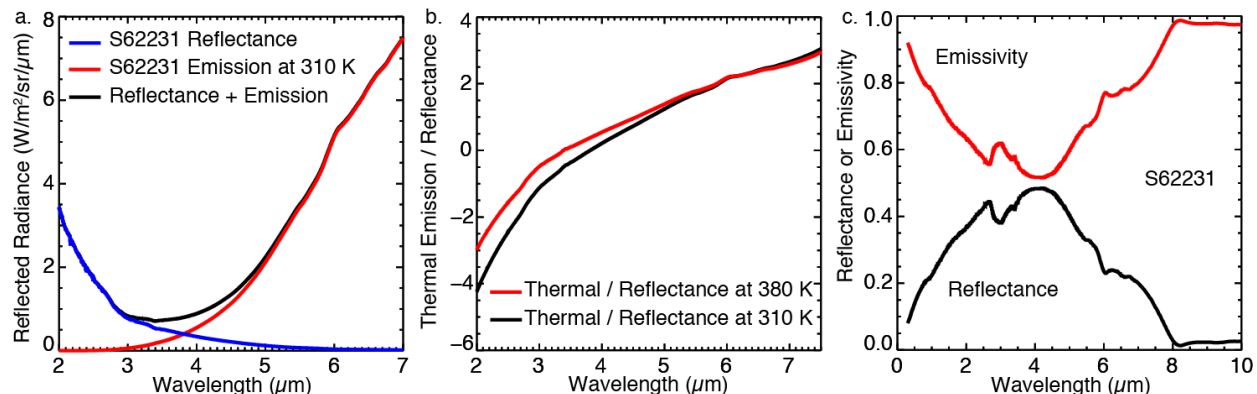
Supplementary Figure 7: Six Clean Clavius Frames. Spectral images of the Clavius region with the oscillation and continuum removed.



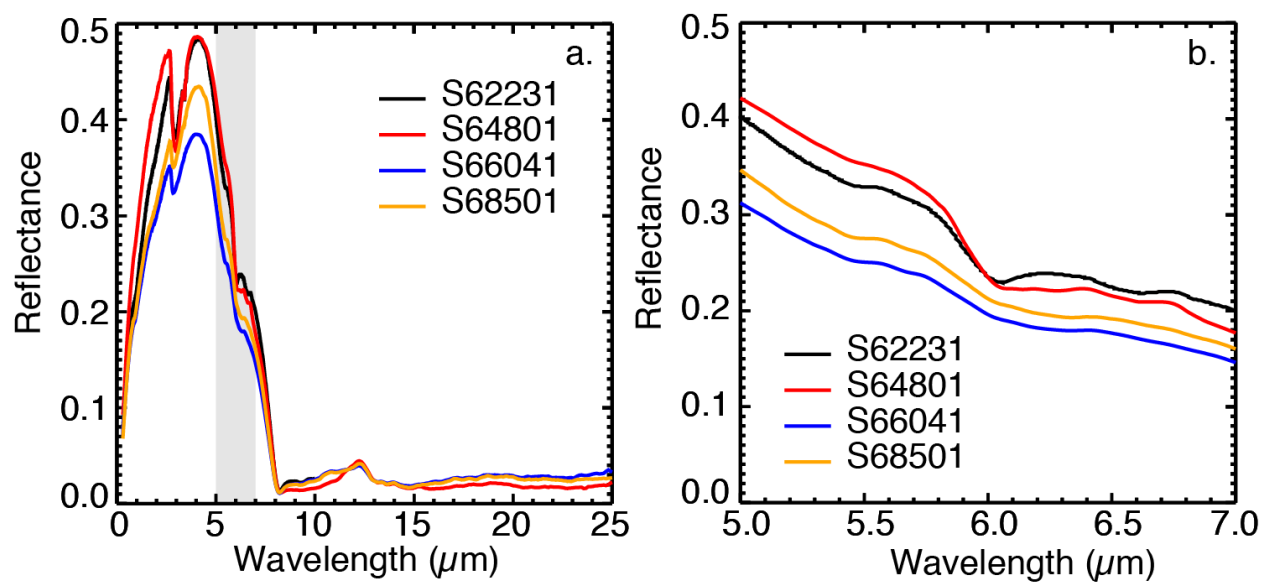
Supplementary Figure 8: Atmospheric water comparison. Residual PWV transmission spectra generated from ATRAN with an altitude of 43,000 ft., a zenith angle of 33°, and a PWV of 3, 3.25, 3.5, and 3.75 μm (black). For spectral shape comparison, a Clavius spectrum showing a strong 6 μm band is shown in red.



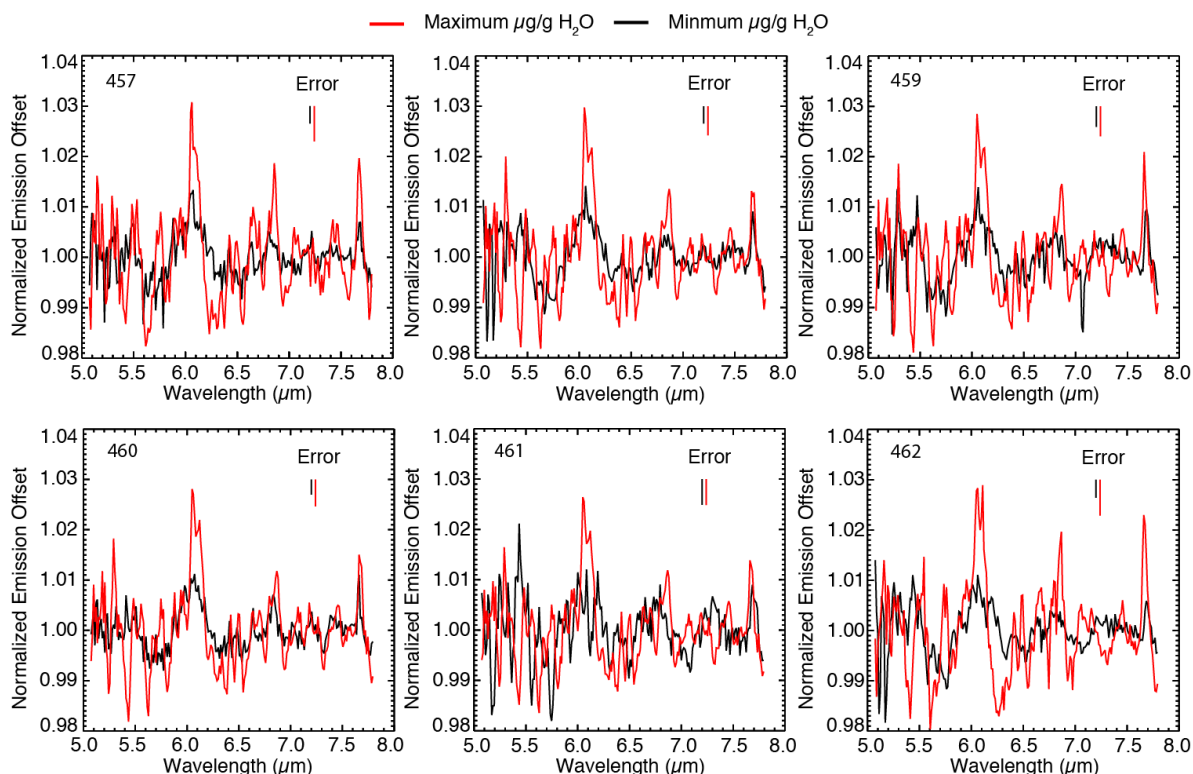
Supplementary Figure 9: Atmospheric water vapor. a.) Transmission of the atmosphere generated from ATRAN with an altitude of 43,000', a zenith angle of 33°, and a PWV of 0.01 μm (red) and 4 μm (black). b.) Ratio of 4 PWV and 0.01 PWV to show only the water vapor spectral structure without other atmospheric constituents.



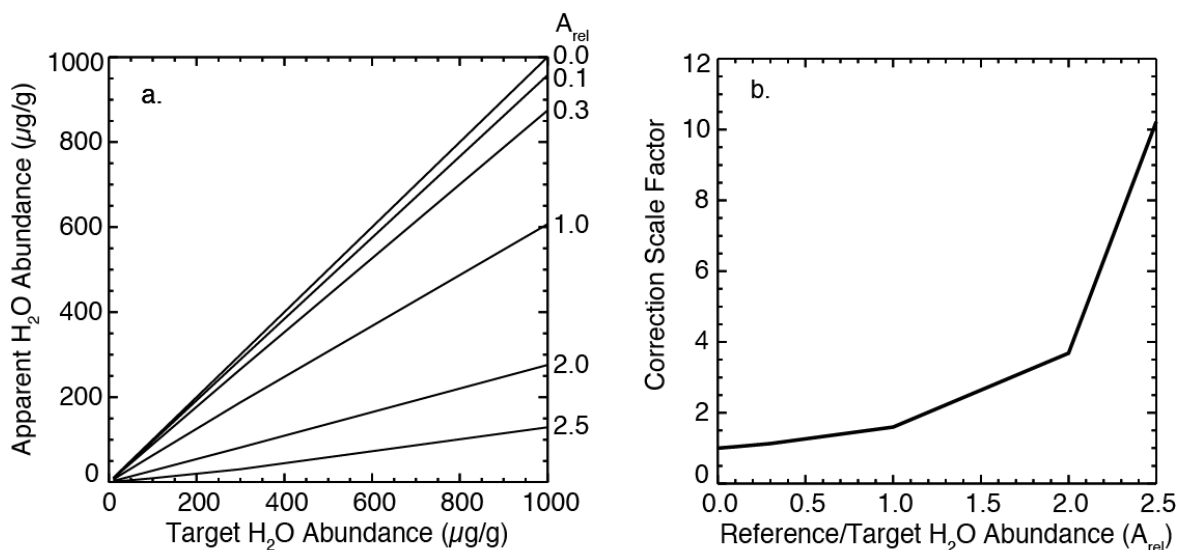
Supplementary Figure 10: Emission vs. reflectance. a.) The reflectance (blue) and thermal emission at 310 K (red) of Apollo sample S62231 and their sum (black) at a latitude of 75° . b.) The log base 10 ratio of thermal emission to reflectance for blackbodies at 310 K (black) for 75° latitude and 380 K (red) for 5° latitude. c.) The reflectance and its Kirchhoff-equivalent emissivity of Apollo sample S62231 used in this calculation.



Supplementary Figure 11: Apollo reflectance. Reflectance spectra of Apollo samples measured at RELAB [Pieters, 1983].



Supplementary Figure 12: Full Clavius spectra. Spectra from all 6 of the Clavius frames showing the minimum (blue) and maximum (red) water abundances and a relatively clean spectrum (black). Unlike Fig. S15, these spectra have a fourth order polynomial continuum removed to show the full wavelength range but spectra using these fits were not used in the abundance analysis.



Supplementary Figure 13: Effect of reference water. a.) The apparent abundance of water that would be measured for varying ratios of water in the reference (A_{rel}), 0 indicated no water in the Reference and 1 indicated equal water in the Reference and Target. b.) Correction factor to apply to the apparent values if the water abundance

Tables

Supplementary Table 1: Flight conditions of each frame and the start and end of lunar latitude

Target		Clavius					
Frame Number		457	458	459	460	461	462
UT		11:37:44	11:38:01	11:38:23	11:38:39	11:39:23	11:39:39
Integration time (s)		4.15760					
Altitude (ft)	Start	43010	43011	43007	43007	43008	43004
	End	43011	43007	43007	43003	43004	42998
Terrestrial Latitude	Start	40.58°N	40.57°N	40.57°N	40.56°N	40.55°N	40.55°N
	End	40.57°N	40.57°N	40.56°N	40.56°N	40.55°N	40.55°N
Terrestrial Longitude	Start	123.68°W	123.73°W	123.79°W	123.83°W	123.96°W	124.00°W
	End	123.73°W	123.77°W	123.84°W	123.88°W	124.00°W	124.05°W
Zenith angle	Start	33.27	33.58	33.26	33.56	33.23	33.54
	End	33.58	33.26	33.56	33.24	33.54	33.22
Lunar Latitude	Start	55.6°S	55.7°S	55.7°S	55.8°S	55.9°S	55.7°S
	End	75.6°S	75.0°S	75.4°S	75.7°S	75.6°S	75.3°S
Lunar Longitude	Start	8.6°W	8.9°W	9.2°W	9.7°W	10.3°W	10.7°W
	End	26.5°W	26.3°W	27.4°W	28.6°W	29.7°W	30.0°W

Target		Mare Reference					
Frame Number		451	452	453	454	455	456
UT		11:30:37	11:30:53	11:31:24	11:31:40	11:32:29	11:32:45
Integration time (s)		3.79847					
Altitude (ft)	Start	43001	43010	43004	43003	43000	43021
	End	43010	43004	43003	43005	43013	43013
Terrestrial Latitude	Start	40.69°N	40.68°N	40.68°N	40.67°N	40.66°N	40.66°N
	End	40.68°N	40.68°N	40.67°N	40.67°N	40.66°N	40.66°N
Terrestrial Longitude	Start	122.49°W	122.54°W	122.62°W	122.66°W	122.79°W	122.85°W
	End	122.54°W	122.57°W	122.66°W	122.71°W	122.85°W	122.88°W
Zenith angle	Start	33.12	33.06	33.09	33.05	33.06	33.02
	End	33.06	33.09	33.05	33.08	33.02	33.06
Lunar Latitude	Start	16.9°N	17.7°N	18.2°N	18.4°N	17.6°N	18.6°N
	End	26.1°N	26.9°N	27.5°N	27.6°N	26.8°N	27.9°N
Lunar Longitude	Start	8.4°E	7.8°E	7.6°E	7.3°E	6.0°E	5.7°E
	End	17.7°E	17.2°E	16.9°E	16.6°E	15.1°E	15.0°E

Supplementary Table 2: Abundance of water estimated in each spectrum from Supplementary Fig. 12.

	Frame					
	457	458	459	460	461	462
Maximum abundance (µg/g)	376	412	404	404	377	401
M³ abundance (µg/g)	238	322	363	329	363	219
Longitude	10.3°W	12.6°W	12.9°W	13.4°W	14.2°W	12.7°W
Latitude	55.4°S	58.8°S	58.8°S	59.0°S	59.0°S	56.2°S
Error (µg/g)	68	56	58	51	50	69
Z score*	3.59	4.52	4.28	4.78	4.63	3.74
Minimum abundance (µg/g)	145	161	157	130	100	132
M³ abundance (µg/g)	698	366	991	101	396	431
Longitude	17.0°W	20.4°W	21.0°W	18.2°W	23.1°W	23.2°W
Latitude	65.3°S	68.7°S	68.8°S	65.3°S	69.3°S	69.0°S
Error (µg/g)	33	33	39	29	49	34
Z score*	3.69	3.68	2.99	3.84	1.41	2.86

*Note the Z-score is not directly proportional to abundance because noise varies from spectrum to spectrum.