Introduction: Infrared absorptions consistent with adsorbed water (H$_2$O, 3 µm) and hydroxyl (OH, 2.8 µm) have been observed by three spacecraft at the Moon [1-3]. However, adsorbed water is not the only possible interpretation of the 3 um absorption band [4]. Physisorbed water (i.e., ice) in vacuum is known to desorb in seconds at 150 K, with desorption rate decreasing exponentially with decreasing absolute temperature. Locations on the Moon receiving significant direct sunlight (which is the light source for the remote detection) will exceed 150 K at local noon, rapidly desorbing all physisorbed water. However, water molecules interacting directly with mineral surfaces can form weak chemical bonds, and greater thermal energy will be required for these water molecules to desorb. An interaction between an adsorbed molecule and the surface that has desorption activation energy exceeding 0.5 eV is defined as chemisorption. If water chemisorbs strongly to the lunar grains with desorption activation energy greater than about 1.0 eV, then some of this water will be bound at high latitudes for geologic timescales. This paper presents experimental evidence for strong chemisorption of molecular water in support of the hypothesis that 3 µm absorptions at high lunar latitudes are due to adsorbed water molecules.

Background: Craters near the lunar poles provide regions of permanent shadow (PSR’s) where the temperature never exceeds 100 K and any exogenic water arriving via comets will be ‘cold trapped’ for billions of years. The LCROSS impact experiment probed one of the coldest PSR’s, Cabeus crater, and found evidence for up to 6% concentration (by mass) of water and ice in the ejecta plume [5]. The likelihood of such cold trapped water-ice was predicted by Watson et al. in 1961 [6]. There is significant interest in studying lunar water in situ for science and resource utilization reasons. Therefore, it is essential to understand the dynamics of this water: where it came from and where else it is expected to be trapped. These questions are being addressed by observations from NASA’s Lunar Reconnaissance Orbiter and by sophisticated computer modeling. Monte Carlo models [7] track water molecules as they migrate about the lunar surface until they either end up in a cold trap or are lost to space. However, existing models are limited by using only the water-ice sublimation energy for the water interaction with the lunar surface and may significantly underestimate the time a migrating water molecule spends on the surface between each migration step. These timescales are important because they define how long a water molecule is exposed on the surface and vulnerable to destruction by high energy radiation (e.g. UV photons, electrons, ions).

This work describes results of laboratory experiments to measure directly the desorption activation energy of water molecules from lunar samples returned by the Apollo missions. It presents a simplified model taking the measured values and estimating how much water can persist (never desorb) on the lunar surface at high latitudes, providing a lower limit for adsorbed water on the Moon. Results of these experiments can be used to support or contradict the likelihood of significant quantities of adsorbed water persisting in solut and/or relatively warm (> 150 K) locations on the Moon. The measurements also provide estimates for water adsorption lifetimes and can be used to enhance existing water migration models.

Samples: Proof-of-concept experiments were conducted with the mineral albite and lunar simulant JSC-1A [8]. The <90 um size fraction of Apollo soil samples 12001 (low-Ti mare soil) and 72501 (highlands soil) were analyzed next. Sample mineralogy is described in Hibbitts et al. [9], the Lunar Sourcebook [10], and references cited therein.

Experimental Methods: TPD experiments were performed under Ultra-High Vacuum (UHV) conditions. The general procedure involves mounting the sample in UHV, cooling to the desired dosing temperature, dosing the adsorbate, and heating the sample at a constant temperature ramp while recording the rate of desorption versus temperature [8].

Results: We have previously reported results of TPD experiments, data analysis, and simplified modeling of water behavior on lunar surrogates, albite and JSC-1A [8]. Similar procedures were followed for collecting and analyzing the TPD data from the lunar samples. However, the surface area of the lunar soils is about one tenth that of the surrogates used, making the experiments much more difficult to perform. The lower signal to noise from the lunar soils necessitates averaging of multiple trials. Additionally, while the controls used in our custom TPD chamber made blank subtraction unnecessary on the surrogates, the lower total signal from the lunar soils also necessitates subtraction of blank trials.
Preliminary results from low temperature dosing of water at <115 K on the lunar soils show evidence for both a broad distribution of molecularly chemisorbed water and bulk water-ice formation, similar to the behavior on the surrogates. Experiments dosing at temperatures above ice adsorption confirm the presence of chemisorbed water molecules up to 400±50 K on laboratory timescales (approximately 1.2±0.3 eV binding energies). Additional experiments are currently underway to better constrain the total water chemisorption (in ppm) and the distribution of desorption activation energies for the water chemisorption. The latest results and interpretation will be presented at the meeting.

Acknowledgments: We are grateful for support of this project from LASER grants NNX11AO54G and Lunar Science Institute grants NNA09DB31A and NNA09DB34A.