

**Condensed Water in the Far-Ultraviolet: Implications for Lunar Hydration.** B. D. Mamo<sup>1,2,3</sup>, U. Raut<sup>2,3,1</sup>, B. D. Teolis<sup>2,3,1</sup>, K. D. Retherford<sup>2,3,1</sup>, J. O. Akene<sup>2,3,1</sup>, J. Brody<sup>2,3</sup> <sup>1</sup>University of Texas at San Antonio, San Antonio, TX, <sup>2</sup>Center for Laboratory Astrophysics and Space Science Experiments (CLASSE), Southwest Research Institute, San Antonio, TX, <sup>3</sup>Southwest Research Institute, San Antonio, TX ([bereket.mamo@contractor.swri.org](mailto:bereket.mamo@contractor.swri.org))

**Introduction:** Far-ultraviolet (FUV) reflectance spectra from the Lyman Alpha Mapping Project (LAMP) spectrograph on board the Lunar Reconnaissance Orbiter (LRO) show evidence for surficial hydrated species on the lunar regolith, with an abundance that varies systematically with latitude and diurnal timescales. While our understanding of the abundance, state ( $\text{H}_2\text{O}$  vs.  $\text{OH}$ ), spatial distribution, and temporal variability of this thin veneer of lunar hydration is evolving and improving, accurately quantifying the  $\text{H}_2\text{O}$  and/or  $\text{OH}$  amounts present in the lunar regolith at the FUV sensing depth and its diurnal variability have proven challenging. At present, LAMP reports upper limits on the dayside lunar hydration abundance of  $< 10^{13} \text{ H}_2\text{O cm}^{-2}$  [1], or equivalently  $< 10$  ppm, several orders of magnitude smaller than the previous estimate of  $< 1$  wt. % relative to lunar soil or 10,000 ppm [2]. LAMP reflectance measurements of the permanently shadowed regions (PSRs), using the interplanetary Lyman- $\alpha$  glow and bright UV stars as illumination sources [3], constrain water ice abundances in these polar cold traps to 1–2 % by weight.

Improving abundance estimates of lunar hydration and its diurnal variability requires accurate optical constants ( $n$ ,  $k$ ) of the endmember species, i.e. lunar regolith and water in the condensed phase. The lunar regolith optical constants in the FUV remains to be characterized; previous efforts [1, 2, 4] have resorted to arbitrary adjustments to the imaginary index,  $k$ , of proxies such as terrestrial basalts [5] to match the LAMP albedos.

FUV optical constants of water ice, while available [6], were compiled from measurements performed by different groups under largely varying experimental conditions; key parameters affecting physico-chemical nature of the ice films such as deposition methods and temperatures, vacuum conditions, etc. differ significantly between several reports. As such, the compilation [6], especially in the FUV, is not as reliable a dataset compared to ones emerging from systematic measurements performed in controlled experimental conditions. To this end, we are working towards deriving FUV (115–200 nm) optical constants of vapor-deposited amorphous and crystalline water ice films from new, robust laboratory reflectance spectra obtained over deposition temperatures ranging from 10 to 140 K.

**Experimental Setup:** We report laboratory reflectance spectra of thin water ice films obtained in the ‘Mordor’ chamber at the Center for Laboratory Astrophysics and Space Science Experiments (CLASSE) at Southwest Research Institute. This ultra-high vacuum chamber (base pressure of  $\sim 10^{-10}$  Torr) supports a 4 K He cryostat that is mounted vertically on a rotatable stage. A 6 MHz, gold-coated quartz crystal microbalance (QCM) is embedded into a copper block that sits at the terminal end of the cryostat. Water ice films are deposited onto the QCM using a micro-capillary doser that exudes a collimated flux of gas towards the cooled QCM. The microbalance reports the areal mass ( $\text{ng/cm}^2$ ) of the condensed films and has a sensitivity of 0.04 monolayers (ML) for water ice. The gold-coating on the front face of the QCM also allows for specular reflectance measurements of films whose column densities are well-constrained.

FUV (115–200 nm) reflectance spectra [preliminary spectrum of a  $0.37 \mu\text{m}$  thick amorphous ice film shown in Figure 1] is measured using a dispersive monochromator (McPherson 234-302) and a Photonics channeltron detector (Model # 5901) coupled to a

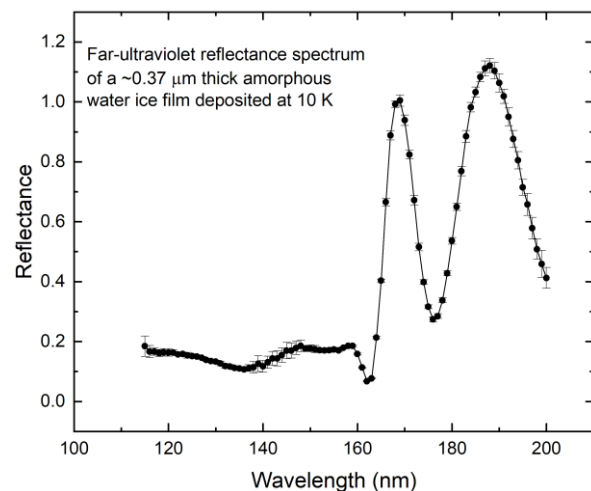


Figure 1: Preliminary FUV spectrum of a  $\sim 0.37 \mu\text{m}$  thick amorphous water ice film obtained using a dispersive monochromator in our laboratory. The ice films was deposited at 10 K. The water ice absorption edge at  $\sim 165$  nm is clearly visible. The oscillation pattern longward of  $\sim 165$  nm is a result of constructive and destructive interference between light reflected from the vacuum-ice interface and the gold substrate.

MDHL (microwave-discharge hydrogen flow lamp) light source [7] with ~5% H and ~95% He. Ice films absorb strongly below 165 nm, with reflectance ~10–20%. Above 165 nm, the ice film is transparent, and the oscillatory reflectance is due to constructive and destructive interference between light reflected from the vacuum-ice interface and the gold substrate.

Optical constants of crystalline and amorphous water ice films derived from our laboratory spectra measured at different thicknesses will be presented with the goal that they can be used to constrain lunar hydration estimates as well as accurately model remote sensing spectra of other ice-bearing planetary bodies.

**References:** [1] Hendrix, A. R. et al (2019) *Geophysical Research Letters*, 46, 2417–2424. [2] Hendrix, A. R. et al. (2012) *JGR Planets*, 117, E12001. [3] Gladstone, G. R. (2012) *JGR Planets*, 117, E00H04. [4] Hayne, P. O. et al. (2015) *Icarus*, 255, 58–69. [5] Shkuratov, Y. et al. (1999) *Icarus*, 132, 235–246. [6] Warren, S. G and Brandt, R. E. (2008) *JGR*, 113, D14220. [7] Chen, Y. -J. et al. (2013) *The Astrophysical Journal*, 78, 15.