Lunar Ultraviolet Reflectance Experiment (LURE): Far-UV Signatures of Water Ice.
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Introduction: Laboratory measurements of the far ultraviolet (FUV) spectral signatures of many common minerals and ices are few to nonexistent. To better interpret Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP) observations of the moon and its permanently shaded regions we've developed an experiment to measure the bidirectional reflectance of water ice and lunar soils samples at FUV wavelengths (1150 – 2000 Å) over various reflectance angles. Named the Lunar Ultraviolet Reflectance Experiment (LURE), our study characterizes the FUV bidirectional reflectance distribution function (BRDF) of water ice and lunar regolith simulants.

Despite the prevalence of UV surface reflectance measurements of planetary objects obtained with modern interplanetary and Earth-orbiting instruments, laboratory ground-truth measurements of FUV spectral properties of materials greatly lag behind similar measurements routinely performed at visible and infrared (IR) wavelengths. A dearth of UV measurements for water ice is particularly surprising, based on its prevalence in the solar system. Working with the vacuum UV lab equipment required to perform reflectance measurements is comparatively difficult, which has precluded these important data.

LRO/LAMP is designed to search for reflected light from the surface of the lunar nightside and permanently shaded regions (PSRs) such as the one within Cabeus crater, which is known through LCROSS impact measurements to contain water and other volatile compounds [1]. Exposed water ice at the surface may be detected with LAMP through a diagnostic water ice absorption edge feature near 160-170 nm. Spectral analysis of PSRs within the LAMP dataset indicate a relative reddening that is best explained with the presence of 1-2% water ice, as recently reported [2]. We've identified the need for improved laboratory measurements of previously identified spectral signatures of water ice and lunar soils at FUV wavelengths to improve this LAMP analysis and improve its search for surface water features.

Previous Studies: UV reflectance spectroscopy is a historically untapped resource for studying airless planetary surfaces (Moon, Mercury, etc.). Visible and IR spectra are common by contrast, since the Sun is brighter at these wavelengths and there are many diagnostic mineral spectral features. Studies of planetary surfaces using FUV reflected light have been limited, focusing on the Moon, asteroids, and the moons and rings of Saturn (e.g., [3, 4, 5]). Nevertheless, the study of surface reflected light at near-UV, mid-UV, and FUV wavelengths has provided much valuable knowledge that is otherwise unattainable at other wavelengths [6].

The only existing FUV measurements of lunar soil samples were performed decades ago [5]. These measurements were rudimentary in nature – e.g., involving only one angle of incidence and reflection, with relatively poor wavelength sampling, and were reported at the time to have an uncertain calibration near Lyman-α (1216 Å). Water frost and a few other volatiles were similarly measured with these Apollo returned samples. A comparison between lab measurements and theoretical predictions of the UV BRDF of water ice has never been performed, which is surprising since such empirical data at visible and IR wavelengths often vary from predictions.

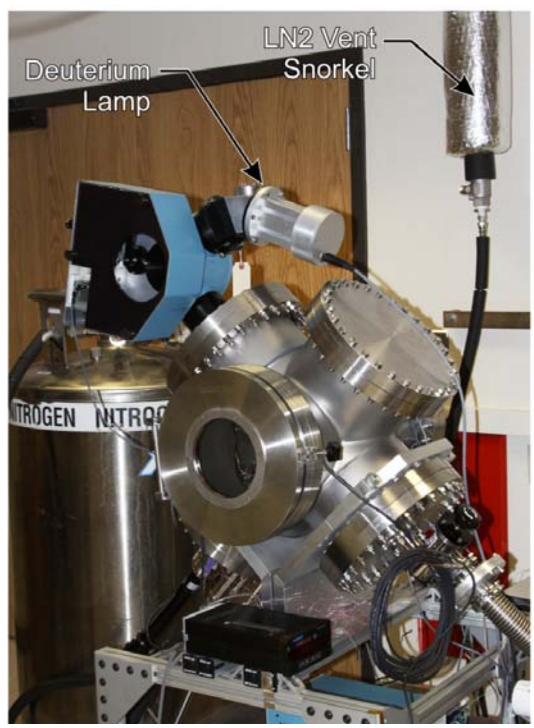

Figure 1: The SwURC facility.

Experimental Setup – the SwRI UV Reflectance Chamber (SwURC): Southwest Research Institute (SwRI) developed a unique, state of the art UV facility to address the need for FUV reflectance measurements. The facility is called the SwRI UV Reflectance Chmaber (SwURC) (Figure 1). The SwURC chamber consists of a six-way cross with 34 cm diameter ports. The six ports include connections to a scanning monochromator, a vacuum pump station, a linear actuator that moves a sample tray in or out of the beam path together with an LN_2 feedthrough to cool the sample tray, rotary and electrical feedthroughs for a photomultiplier tube (PMT) detector, a load-lock door for easy sample exchanges, and lastly a blank plate for future additional instruments. The chamber completed its calibration phase in the last year.

Our technique alternates measurements of the horizontal sample using a monochromatic beam of light from a deuterium lamp at 45° incidence, and the PMT detector rotated at multiple emission angles relative to the sample (-15° to ~85°). In addition, the direct beam orientation is measured for reference by moving the sample tray away from the beam. In this way, we bypass the need for calibration reference standards of diffuse reflectance (which are poorly defined for the FUV). The spectral resolution is 5 Å.

Early LURE Measurements: The LURE set of measurements to date include the JSC-1A lunar simulants at course (1 mm – 5 mm) and fine (< 20 μm) grain sizes. Crystalline water ice is formed in situ using our custom made liquid N_2 cryocooling feedthrough.

Initial measurements of water ice, lunar simulants, and mixtures of the two [7] are being repeated with improved counting statistics and calibration factors. Figure 2 shows the initial LURE water ice reflectance spectrum. The low (few percent) reflectance shortward of 160 nm and steep absorption edge from 160-170 nm agrees well with models and other recent lab measurements [4]. We will report water ice and lunar simulant measurements with improved signal to noise ratio and calibration, particularly in the 170-200 nm range.

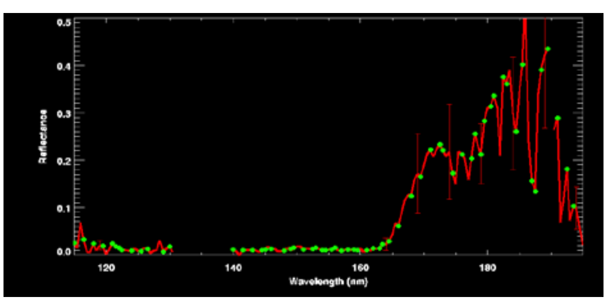

Figure 2: Initial water ice reflectance spectrum at 45° emission angle.

Future LURE Work: The lunar simulants measured in this study are a precursor (a demonstrator) for obtaining and measuring Apollo samples. We plan to repeat the Apollo returned sample measurements performed by Wagner, Hapke, and Wells [5] with better wavelength and angular resolution. Additional lunar simulant types are also being procured.

Future Objectives for the SwURC: This new facility is also well suited (e.g., highly adaptable and customizable) to measurements of numerous planetary ices and minerals, meteorites and returned samples, and other optical materials. Planned near-term measurements include, among others: argon frost to support LAMP, an aubrite meteorite sample to support Rosetta/Alice, and N_2 frost to support New Horizons/Alice. We plan to take community requests for measurements (kretherford@swri.edu), and to collaborate with others.

Summary: Initial FUV bireflectance measurements of lunar simulants and water ice have been completed and are being refined with improved quality. We report the reflectance spectra of our water ice and lunar simulant measurements together with angular distribution functions for each.

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