LONG-RANGE ACTIVE LASER SPECTROSCOPY INSTRUMENTS FOR PLANETARY EXPLORATION: LIBS FOR ELEMENTAL ANALYSIS OF LUNAR REGOLITH.

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Introduction: Remote sensing data from several space missions show that the Moon harbors significant quantities of water in permanently shadowed craters near the poles. Data from the M^3 spectrometer and the mini-SAR radar onboard the Chandrayaan-1 spacecraft suggest the presence of water or hydroxyl in the regolith and that the water might be present as ice in those regions. The LCROSS impact experiment confirmed abundant volatiles in the lunar South Pole crater Cabeus, including water, light hydrocarbons and carbon dioxide. Lunar mineralogies at the poles could show unique features and chemistries different from those of the Apollo Missions. New materials could include hematite, recently unexpectedly detected at high lunar latitudes [1]. In permanently shadowed regions, various ices, and various volatile compounds, including organics, could be present [2]. The polar environment may also exhibit alteration minerals as resulting from reactions between silicates and volatiles fueled by impacts [3]. The detection of water on the moon could enable its use as a resource and would better shape our understanding of the evolution of the Moon. As these deposits can potentially be sourced, the form, concentration, amount and spatial distribution of the volatile species have become strategic knowledge gaps in the path to lunar human exploration.

A versatile sensor able to detect a wide range of compounds is necessary for understanding this unique environment. Active remote time-resolved (TR) spectroscopic techniques are being recently developed and can perform laser induced spectroscopy measurements at great distances. Raman detection has been reported at ranges over a km [4] and a two-component remote focus Raman and LIBS system have reported long-range measurements (over 100 m) using relatively low laser power [5].

Time-resolved Raman spectroscopy can be used to detect anhydrous and hydrated minerals, glasses, organics, and various-types of ices [6, 7]. In this presentation, we will show long-range remote focus LIBS measurements using low laser energy pulses along with fiber-optic coupled as well as directly coupled telescopic systems. Studied materials are related to lunar exploration but carried out at 1 atmosphere pressure and room temperature or with the samples cooled down to 77 K with the help of liquid nitrogen. Systems like the active time-resolved laser setups and measurement methods described here could be used on traditional or newly conceived commercial lunar landers and Rovers. New more sensitive LIBS setups are also needed as LIBS spectra of lunar related materials under reduced pressures relevant close to lunar near-vacuum conditions have been previously reported to 1.5 m showing decreased signal intensities for very low pressures [8]

System Format: A remote LIBS system can be easily combined to perform Raman and Laser Induced Time Resolved fluorescence [9]. Systems main components are a pulsed laser, beam expander, and turning mirrors to provide a coaxial collimated beam to aim on a remote sample small optical setup with a large spot size through a 45-degree mirror and short focal length lens. The detector side consists of a telescope as collection optics, a coupling lens, and a spectrograph with time resolving capabilities. For this study we used a 4-inch telescope coupled with triple Ocean Optics fiber-coupled OOLIBS spectrometers and a Big Sky Nd-YAG laser providing 9 mJ of 1064 nm pulses at 20 Hz (Figs. 1 and 2). This system is similar to the ChemCam MSL instrument setup [10]; and a 5-inch telescope.

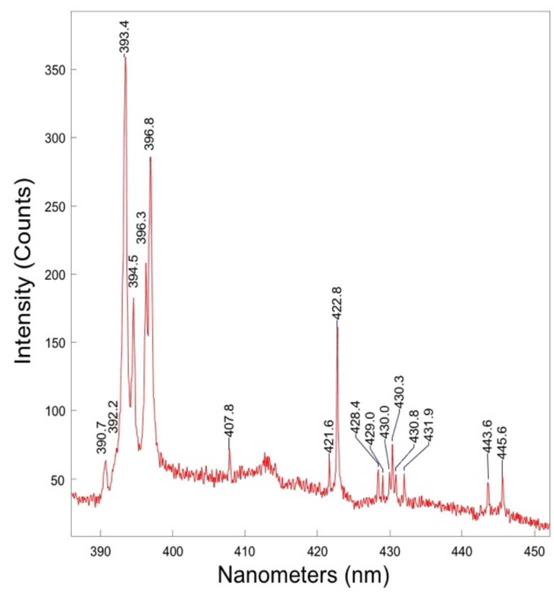
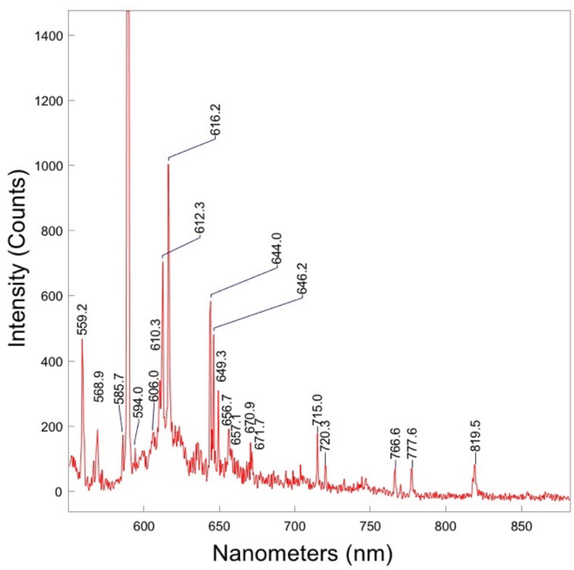


Figure 1: Remote focus LIBS measurement of albite with short focal lens near the sample, 8 meters rage, blue spectral range.

In a second system, we directly coupled to a lens-grating-lens spectrometer containing volume phase holographic (VPH) transmission gratings attached to an intensified CCD camera collecting light from the illuminated remote sample This system is analogous to the optical setup of the SuperCam instrument in the

Perseverance rover, however we have the telescope directly coupled to the spectrometer and our telescope is larger at 8-inch diameter [11]. System controls and collection data are achieved by means of computer software. The results are shown in Figure 3.

Results: Figures 1-3 show two components remote focus LIBS measurements of a feldspar and a possible analog for a lunar basalt showing water and various organics. The feldspar spectrum shows Ca libs lines in the sodium end member of the plagioclase feldspar sodium solution: albite. Na LIBS lines are the strongest in the spectrum, consistent with data reported for LIBS measurements of albite at room pressure and



temperature [12].

Figure 2: Remote focus LIBS measurement of albite with short focal lens near the sample, 8 meters rage, VIS-NIR spectral range

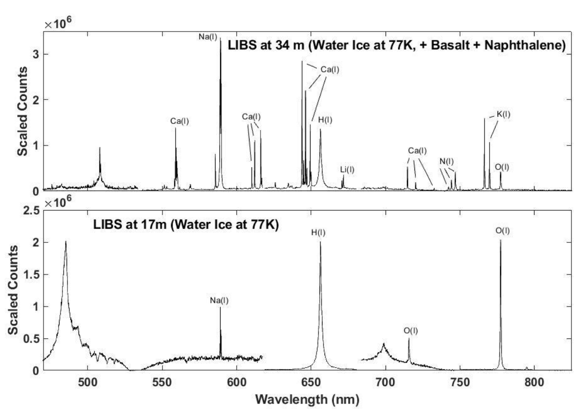


Figure 3: Remote focus LIBS measurements carried out at 17 and 34 m range using a short focal length lens near the sample. The bottom trace shows a LIBS spectrum of H_2O ice cooled to 77 K with liquid N_2. The top trace shows a LIBS spectrum of a mixture of H_2O ice layered with basalt powder, and naphthalene cooled to 77 K. For the ice measurements (bottom trace) the laser energy was 4 mJ/pulse of 532 nm and ICCD gate delay was set to 600 ns and the sample interval was 5 µs. For the ice + Basalt + naphthalene measurements (top trace) the laser energy was 10 mJ/pulse and ICCD gate delay was set to 800 ns and the sample interval was 5 µs.

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