

**LUNAR ELEMENTAL ANALYSIS WITH REMOTE LASER INDUCED BREAKDOWN SPECTROSCOPY (LIBS).** S. M. Clegg, R. C. Wiens, D. J. Lawrence, and J. E. Barefield, Los Alamos National Laboratory (sclegg@lanl.gov).

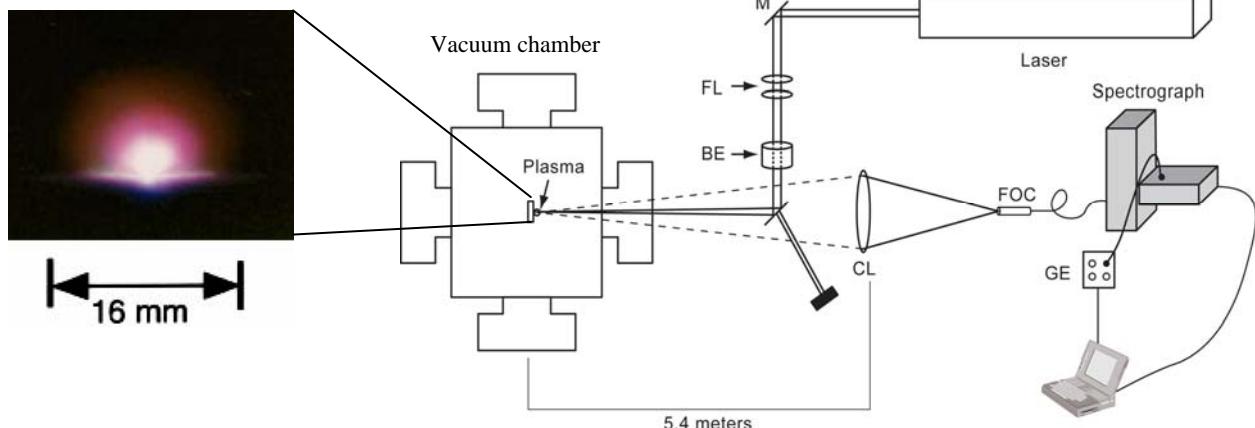
**Introduction:** In order to gain a full understanding of the role hydrogen and other volatiles plays in the lunar polar regions, in situ measurements will need to be made on the lunar surface in permanently shaded regions. Key information that needs to be known includes the hydrogen and volatile inventory of lunar soils at the surface as well as their spatial distribution. There are indications from orbital data that the polar hydrogen may be covered by a desiccated layer up to 20 cm thick [1]. It is therefore also important to understand the volatile content of lunar soils as a function of depth into the lunar soil.

Remote Laser Induced Breakdown Spectroscopy (LIBS) is an emerging elemental analysis tool for planetary sciences. The ChemCam instrument selected for the Mars Science Laboratory (MSL) rover includes a remote LIBS instrument that will probe samples up to nine meters away from the rover mast. LIBS involves focusing a laser on to the surface of a sample to generate a plasma. The emission from the plasma is indicative of the elements present in the sample.

In simulated Mars-based applications[2], LIBS has been used to probe water ice as well as water ice soil mixtures for in situ and stand-off ( $> 6.5$  m) distances. LIBS is therefore a potential technique for using in the lunar polar regions. We note that remote laser Raman techniques have been suggested for dual-use with LIBS measurements[3]. In such a case, both elemental and chemical species information of polar lunar soil could be obtained in a single instrument.

**LIBS Challenges for Lunar Applications:** The lack of a lunar atmosphere creates a significant scientific and technical challenge for remote LIBS. LIBS is exceedingly sensitive to the local atmospheric pressure. At pressures greater than 100 Torr, the LIBS plasma is perturbed as it expands against the atmosphere and collisional deactivation reduces the plasma intensity. The intensity of the LIBS plasma is brightest when the atmospheric pressure ranges from 10 to 100 Torr where the atmosphere prevents the plasma from expanding beyond the optical field of view while collisional influences are significantly reduced. However, as the atmospheric pressure is further reduced, the plasma expands beyond the field of view and the plasma intensity is further reduced.

**Experimental Studies of LIBS in a Low Vacuum Environment:** Figure 1 contains a diagram of the experimental setup. A Nd:YAG laser operating at 1064nm (10Hz repetition rate and 10ns pulse width) was focused on the surface of a basalt sample.[4] The laser ablates material from the surface, generating an expanding plasma containing electronically excited ions, atoms, and small molecules. As these electronically excited species relax back to the ground state, they emit light at wavelengths characteristic of the species present in the sample. The sample was placed in a vacuum chamber positioned 5.4m away from the laser and telescope used to collect the some of the emission. The LIBS emission collected with the telescope was directed into an Ocean Optics HR2000 dis-



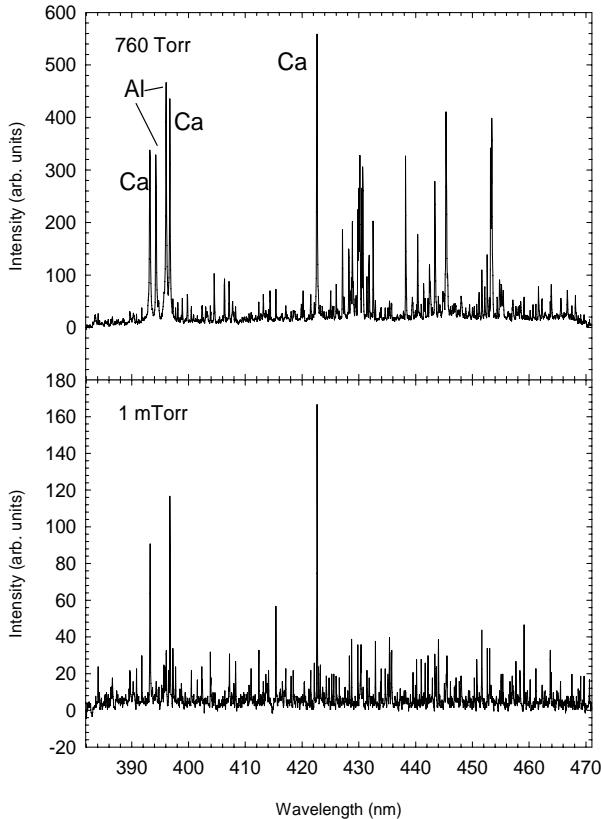
**Figure 1:** Right. A diagram of the experimental design. Left. A picture of the LIBS plasma under 7 Torr CO<sub>2</sub>. The optical elements identified within the figure include M = mirror, FL = Focusing Lens, BE = Beam Expander, CL is the Telescope, FOC = optical fiber.

persive spectrometers through a 30um, 0.12NA optical fiber.

The ChemCam instrument will actually include three spectrometers optically similar to the Ocean Optics HR2000 commercial spectrometers. The three dispersive spectrometers are used to detect emission in the 220 – 325 nm (UV), 380 – 470 nm (VIS), and 490 – 800 nm (VNIR) spectral regions.

The experiments presented here were placed in a vacuum chamber and pumped down to 1mTorr. Admittedly, this is not nearly similar to the lunar atmospheric conditions. As a point of reference, some experiments were also conducted at 760 Torr.

**Results and Discussion:** Figure 2 contains two LIBS spectra of a BHVO-2 Hawaiian basalt sample acquired from the USGS. The top spectrum was collected under terrestrial atmospheric conditions and the bottom spectrum was collected under 1 mTorr. Both spectra demonstrate the complex structure observed from the LIBS plasma. Each of the peaks represents emission from the elements present in the sample and some of the elemental emission lines are identified in the figure.



**Figure 2:** LIBS spectra of BHVO-2 basalt standard acquired under 760 Torr (Top) and 1mTorr (bottom). The sample was placed 5.4m away from the laser and telescope as depicted in Figure 1. The most prominent peaks in both spectra are from Ca and Al emission while most of the remaining peaks are from Fe.

The figure clearly depicts the reduction in emission intensity as the vacuum chamber is evacuated. The calcium emission lines at 393.37, 396.85 and 422.6 are the strongest emission lines in both spectra. As the pressure is decreased from 760 Torr to 1mTorr, the peak intensity at 422.6nm is 558 counts to 167 counts. Furthermore, the intensity across the entire spectrum was reduced by a factor of five as the total integrated intensity reduced from 68651 counts to 13518 counts.

**Future Work :** We plan to carry out future experiments where we will use lunar soil simulants in place of the BHVO-2 basalt. We will carry out the tests in as low a vacuum that is achievable in our current experimental set up. In addition, as part of these experiments, we will emplace various amounts of H<sub>2</sub>O in the lunar soil simulants to measure the sensitivity of the LIBS technique for detecting and measuring H<sub>2</sub>O in vacuum-like conditions. Further work can include testing the soil simulant under cold conditions that are closer to the lunar polar environment.

**References:** [1] Lawrence et al., (2006) JGR-Planets, 111, 10. 1029/2005JE002637. [2] Arp Z.A. et al. (2004) Applied Spectroscopy, 58, 897 [3] Wiens R.C. Spectrochimica Acta A (2005) 61, 2324 [4] Thompson J. R. (2005) *JGR-Planets*, 111, E05006.