CLOSE-RANGE IN-SITU LIBS (LASER INDUCED BREAKDOWN SPECTROSCOPE) EXPERIMENT ABOARD THE CHANDRAYAAN-3 PRAGYAAN ROVER: OPERATIONS AND INITIAL RESULTS

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Introduction: The recent Indian mission to the Moon, Chandrayaan-3 [1-2], which was launched on 14 July 2023 by the ISRO (Indian Space Research Organization), marked a historic milestone on 23 August 2023 by soft-landing a craft, named Vikram in the southern higher latitude (latitude: 69.367° south, longitude: 32.348° east) lunar region. In the aftermath of soft-landing, the Pragyaan rover that was housed in the lander craft's belly has touched the moon's surface by gently ramping down from the lander's platform in the very early morning hours of August 24, 2023. The principal scientific objective of the Pragyaan rover is to conduct in-situ lunar surface elemental composition in the southern higher latitude regions. One of the scientific instruments of the Pragyaan rover, the LE-LIBS (Low-energy Eyesafe Laser Induced Breakdown Scope) is the first laser-induced plasma spectroscopy science instrument to operate on the Moon to date. The LE-LIBS is primarily aimed at identifying and deriving the abundance of elements that are commonly found in lunar rock-forming minerals, i.e. O, Na, Mg, Al, Si, K, Ca, Fe, Cr, Mn, Ti, etc. and the possible detection of volatile and trace elements (H, C, N, S and P) in the vicinity of the Chandrayaan-3 landing site. Through this paper, authors will present salient instrumentation aspects of the LE-LIBS payload, details of the executed onboard operations and initial results.

LE-LIBS Configuration: The LE-LIBS payload, which was developed based on the laser-induced breakdown spectroscopy technique, employs low-energy (≤ 3 mJ) and eye-safe wavelength (1535±1 nm) laser pulses as the ablation force for the execution of close-range in-situ elemental investigations on the lunar surface. The divergence of the laser beam is ~0.43 mrad and the spot-size on the lunar surface is ≤ 100 μm at a working distance (height) of 205 mm from the rover chassis. Collection Optics Unit (COU) is a 3 lens and 2 mirror elements based folding geometry, while the spectro-graph unit was built on flat-field configuration comprising a holographic aberration-corrected reflective grating and the CCD (charge couple device) as the detector. The engineering aspects of the LE-LIBS are described elsewhere [3]. The total payload weight is about 1130 grams with a footprint envelope of 180 mm (L) x 150 mm (W) x 80 mm (H). Fig. 1 shows the LE-LIBS that was housed beneath the Pragyaan rover's chassis. To validate the performance and to ensure successful operation onboard the Chandrayaan-3 rover, several pre-flight tests at the system-level and rover-integrated level were devised and performed. Spectral database was generated employing diverse standard/certified reference soil powders in a high-vacuum environment of ~ 2×10^{-7} torr. Suitable data pre-processing approaches [4] were optimized to generate a clean plasma emission spectrum for detailed analysis.

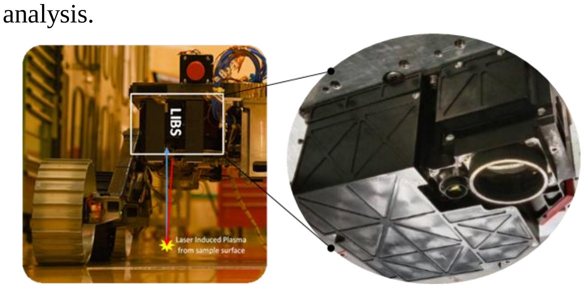

Fig. 1 The LE-LIBS payload mounted to rover's chassis at the bottom (left); the flight-model of the LE-LIBS (right)

Onboard operations and initial results: The LE-LIBS, which is the first of its kind to execute in-situ close-range elemental investigations on the lunar surface, operated for the first time on August 25, 2023, at 10:42:21 UTC for a duration of 35 seconds. The operation was started after the selection of a suitable observation location. Based on the executed operations, the LE-LIBS performance was found nominal. The first LIBS emission spectrum of the lunar regolith was recorded from a southeast site (with respect to the landing location), while the last operation was performed on September 2, 2023, for 50 seconds on a northeast site. The LE-LIBS payload was turned ON 66 times and performed investigations on 25 different sites in various locations, viz., plain regions, the rim of the craters, disturbed surface by the rover wheels etc. The onboard experienced base temperature was observed within the operating temperature range of the instrument [2]. Fig. 2 shows the horizontal bar plot representing the number of LE-LIBS operations versus the day of the operation. The instrument ablated the lunar soil/regolith at different places and collected the laser-induced plasma emission signal for more than 750 laser shots. A suite of tele-commands are uplinked from the ground station varying in parameters viz., laser pump current, delay time, acquisition time, number of laser shots, mode of operation, background registration sequence etc. Plasma emission was recorded for every laser shot and the non-laser background signal was acquired before the plasma emission for the same integration time at the same site.

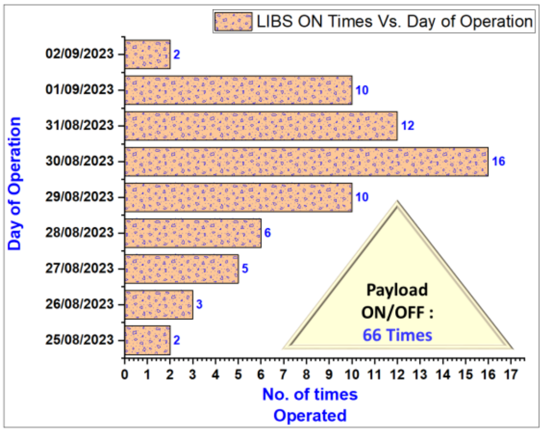

Fig. 2 The LE-LIBS payload ON times versus day (earth day) of the operation

Initial observations by LE-LIBS: The illumination conditions, target site nature and the rover body plane tilts have resulted in various kinds of non-laser bakground and laser-induced plasma emission spectral signatures. A few of the operations resulted in a flat-background, while for a few, the non-laser background was saturated. Similarly, acquired plasma emission spectra too have shown different signatures, a few spectra populated with intense emission peaks and a few having a very low number of emission peaks (dominated by the non-laser background).

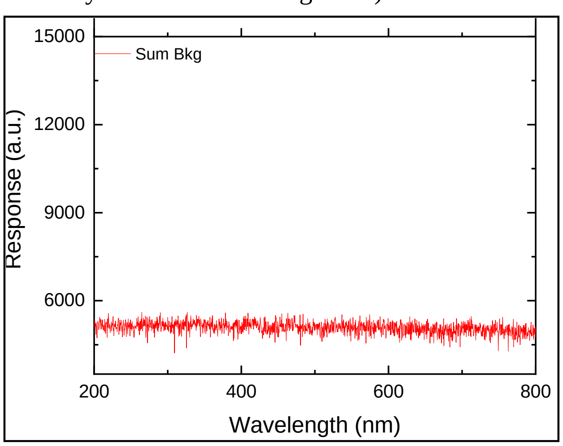

Fig. 3 Unprocessed non-laser background signal of lunar regolith as recorded by the LE-LIBS instrument

Fig. 3 presents one of the acquired unprocessed non-laser background spectra in the spectral range of 200 nm – 800 nm, while Fig. 4 shows the integrated (for 3-laser shots) background subtracted and denoised plasma emission spectrum of the lunar regolith.

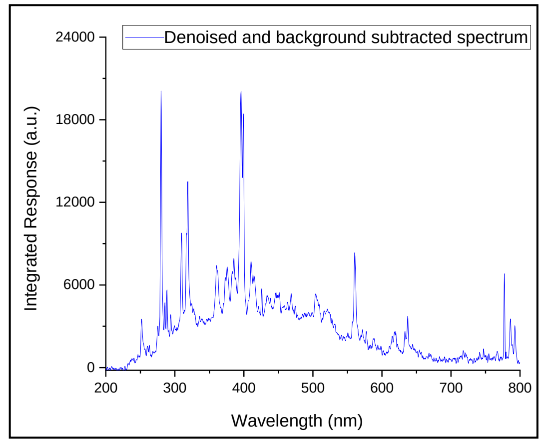

Fig. 4 Background-subtracted and the denoised LIBS emission spectrum of the lunar regolith as captured by LE-LIBS instrument aboard the Chandrayaan-3 Pragyaan rover

These observations concluded the effective operation and performance of the LE-LIBS instrument in an air-less planetary body (the Moon, here) environment. Preliminary analysis of the first-ever recorded LIBS emission spectrum of the lunar regolith at a site, a few couple of meters away from the landing point has indicated the presence of elements viz., O, Al, Si, Ca, Fe, Ti, Mn, and Cr. Later investigations are found to be even more promising regarding a few vital trace and volatile elements, which will be communicated afterward.

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