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Science enabled by LIBS exploration of planetary surfaces

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Abstract

Laser Induced Breakdown Spectroscopy (LIBS) is a versatile chemical analytical technique that can provide significant benefits for the study of surface compositions on landers, hoppers, or rovers on Venus, the Moon, asteroids, comets, outer moons (including Titan), and Mars.

1. Introduction

The LIBS technique is based on the use of a pulsed laser that ablates a small fraction of a target of interest generating a plasma whose light is collected and analyzed by spectroscopy [see e.g. 1]. We present here the science rationale for using LIBS to explore planetary surfaces of the solar system.

2. LIBS use on Mars

On-board the NASA Mars Science Laboratory rover, ChemCam is the first LIBS instrument operated on the surface of another planet. Its construction and calibration procedures are detailed in [2, 3, 4, 5]. The instrument has the ability to analyze in few minutes the chemical composition of targets up to 7 m from the rover after first removing the martian eolian dust that systematically covers each target as illustrated in Fig. 1. Its fine-scale analysis (spot size of 300 to 500 microns) gives detailed variations in the chemical composition of targets of interest, as shown in Fig. 2.

Amongst the results that have been acquired with ChemCam on Mars [6], the following illustrate the advantages of LIBS for quick chemical survey of a planetary surface: quantification of the major elements constituting a target (O, Na, Mg, Al, Si, K, Ca, Ti, and Fe); detection of non-metallic elements especially volatile ones (H, C, O, P, S, Cl); first detection of F on Mars; capacity to detect various minor elements (Li, Rb, Sr, Ba, Cr, Mn, Ni, Zn); chemical survey of igneous and sedimentary rocks at Gale; determination of the composition of calcium sulfate veins; specific detection of H, Mn, and Mg enrichments; assessment of the composition of Mars eolian dust, soils and dunes (for a review of ChemCam results, see [6, 7]).

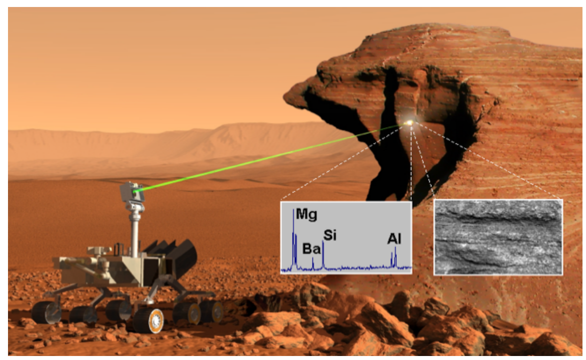

Figure 1: *Operational principle of ChemCam/LIBS on Mars (Credit CNES/NASA).*

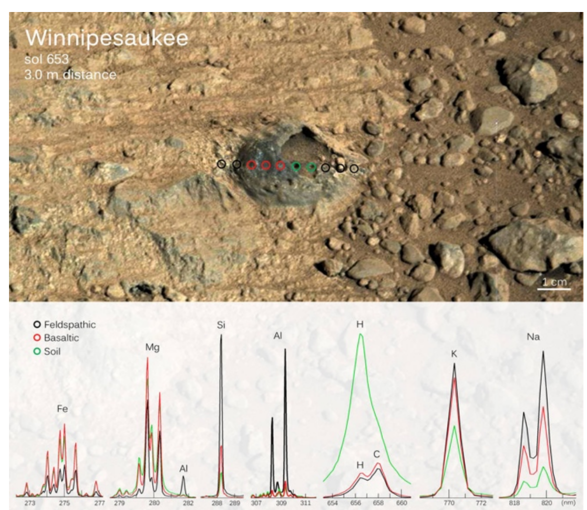

Figure 2: *Fine scale compositional variations detected by ChemCam on Mars (Credit NASA/JPL).*

In short, the Mars surface and atmosphere provide good conditions for the application of LIBS, allowing ChemCam to assess the diversity of the geological materials. Future instruments such as SuperCam [8] and MarsCoDe [9] will continue the exploration of Mars with LIBS in the near future.

3. LIBS application on Venus

Quantitative chemical and mineralogical investigations are required to better understand the origin of Venus' surface and the interaction of the rocks and minerals with Venus' atmosphere. The surface conditions (T~735 K; P~92 bars) are very challenging for any kind of investigation. In situ investigations must be completed within several hours before the lander is overcome by environmental conditions. Remote measurements made from within the safety of the lander are ideal as they reduce the level of risks, including the use of sampling hardware and the extended time required to deliver samples to instruments inside the lander. The LIBS technique could be used to acquire thousands of high-resolution chemical composition analysis of the surface of the landing area within two hours. The feasibility of such measurements was demonstrated with the VEMCam prototype at LANL [10].

4. Using LIBS on airless bodies

The Moon, asteroids, comets and other airless bodies present another challenge for LIBS. Without atmosphere to prevent its expansion, the plasma intensity is reduced. However, the capability of LIBS instruments to do chemical analysis remains intact as demonstrated in laboratory measurements [11] and as expected to be used on the Moon later this year by the LIBS experiment on Chandrayaan 2 [12]. The ability of LIBS to quickly survey an area and determine its chemical variations at a sub-mm scale remains of high interest to quickly classify soils and rocks and possibly help in the selection of materials of interest for future sample returns.

On the Moon, LIBS can help classify highland rock types, mare basalts, KREEP and Mg-rich materials. Furthermore, its sensitivity to volatile elements and especially H, make it valuable for possible future in situ resources prospecting and utilizations [11]. In the case of primitive small bodies, the rock classification and volatile detection will be similarly valuable. More specifically, the chemical composition obtained using LIBS could be compared with known meteoritic samples to untangle the origin of some of the extra-terrestrial materials found on Earth [13]. Additionally, the capability for carbonaceous matter detection would be of high interest to analyze possible prebiotic material [14]. Furthermore, LIBS analyses are starting to make significant progress to quantify low isotopic ratios, such as D/H, which would be crucial to better understand the origin of small bodies [15].

The same rationale can be used for the exploration of the satellites of outer planets rich in water and with possible exobiological interest, such as Europa and Enceladus. Titan is a special case where the dense atmosphere and the presence of hydrocarbons would lead to a strong C signal in the LIBS plasma [16].

5. LIBS implementations

Depending on the resources available and the target of interest, a variety of configurations are possible for LIBS instruments. While a full spectrum coverage (200-900 nm) at decent resolution (~0.02 nm) is recommended, specifically minimal designs to analyze targets at a given distance or to focus on certain lines of interest can be envisioned. Combined implementations of LIBS with other techniques such as Raman and IR spectroscopy, mass spectrometry, or even acoustical sensing have successfully been implemented in the laboratory. The ease of use and rapidity of the LIBS analysis will also make it a viable candidate for use as a handheld device in future human exploration of extra-terrestrial surfaces.

6. Concluding statement

This presentation results from an International Team Meeting at the International Space Science Institute (ISSI) in Bern earlier this year, in which all of the authors were participants. The weeklong discussion resulted in many ideas for how LIBS can benefit planetary exploration on many fronts. A second meeting is planned for ISSI in Beijing.

Acknowledgements

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