Custom Setup for LIBS Plasma Imaging in simulated Martian conditions

D. S. Vogt[a], S. Schröder[a], S. Frohmann[a], K. Rammelkamp[a], P. B. Hansen[a], S. Kubitza[a], H.-W. Hübers[a,b]

[a]*Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Berlin, Germany*
[b]*Humboldt-Universität zu Berlin, Institut für Physik, Berlin, Germany*

1. Introduction

Laser-Induced Breakdown Spectroscopy (LIBS) permits rapid in-situ multi-elemental analysis without sample preparation and with optical access only [1]. It has already been proven to be a very useful technique for in-situ geochemical analysis of the surface of Mars. The first extraterrestrially employed LIBS instrument ChemCam [2, 3] onboard the Mars rover Curiosity will soon be followed by its successor SuperCam on NASA's upcoming Mars 2020 rover mission [4] and by another LIBS instrument on the rover of the Chinese HX-1 mission.

The pressure and composition of the ambient gas affect the formation, the evolution, and the emission of the laser-induced plasma [1, 5, 6]. Martian atmospheric pressure (6–10 mbar at surface level in Gale Crater [7]) is close to ideal for the laser-induced plasma, resulting in high signal intensities [6]. However, the low ambient pressure also influences the plasma emission in ways that are not yet fully understood. The reduced plasma confinement is expected to lead to a higher relevance of dynamic processes within the plasma. It is also expected that the temperature gradients within the plasma are more significant, leading to different regions of excitation. In this case, the commonly held assumption of a uniform plasma will not be valid anymore.

We have developed a custom plasma imaging setup which allows us to investigate laser-induced plasmas in simulated Martian atmospheric conditions. Our goal is to provide a better understanding of the particular characteristics of Martian LIBS plasmas, their dynamics and typical spatial and temporal evolution by means of time-resolved plasma imaging.

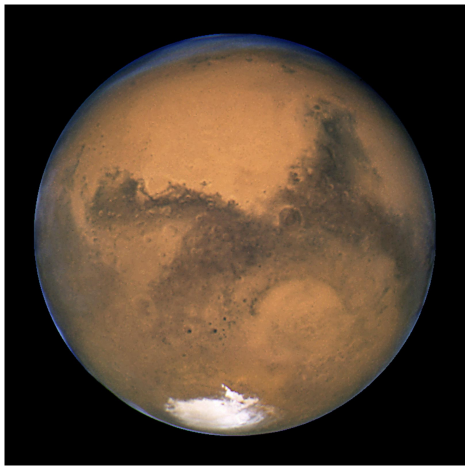

Figure 1: Close-up of Mars by NASA's Hubble Space Telescope. Credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA).

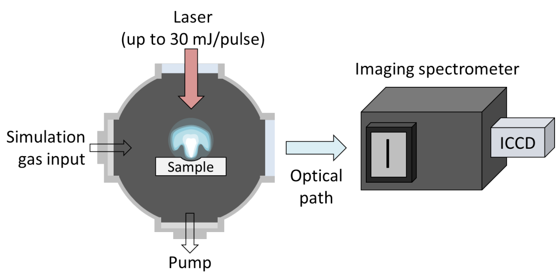

Figure 2: Schematic of the plasma imaging setup. The plasma is created within the simulation chamber by directing the laser beam through a window above the sample. The emission is collected through a window on the side of the chamber and focused onto the slit of the Kymera 328i. The ambient gas in the simulation chamber and its pressure can be changed in order to simulate different planetary environments.

Email addresses: david.vogt@dlr.de (D. S. Vogt), susanne.schroeder@dlr.de (S. Schröder)

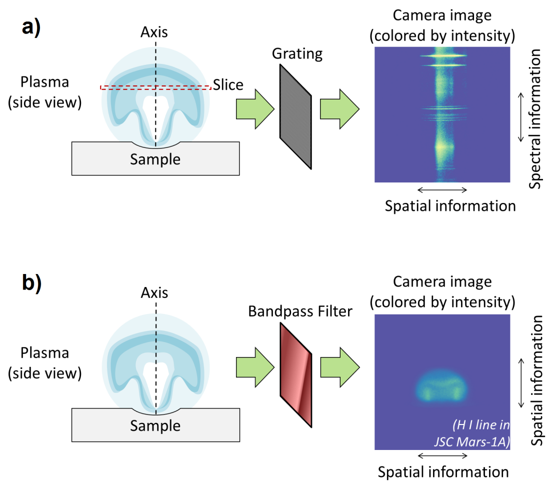

Figure 3: Schematics of the two different ways the plasma imaging setup is used. a) Spatially-resolved LIBS spectra are measured for multiple thin slices of the plasma at different heights. b) The whole plasma is imaged using a spectral filter in order to get the emission of a specific signal in a single measurement.

2. Plasma Imaging Setup

The time-resolved plasma imaging setup at DLR Berlin was recently implemented and combined with a simulation chamber to experimentally simulate different low-pressure environments [8]. Fig. 2 shows a schematic of the setup. A Nd:YAG laser (Quantel Viron, 1064 nm wavelength, 8 ns pulse width, up to 30 mJ/pulse) is used to generate the plasma. The plasma emission is detected with the the Andor Kymera 328i imaging monochromator, which is equipped with the Andor iStar DH334T ICCD with the 18F-E3 photocathode model. This time-gated ICCD enables the time-resolved measurements and is synchronized with the Nd:YAG laser in order to start measurements at a precise time after plasma initiation. We use three different gratings with high efficiency in the UV, the visual and the near-infrared wavelength ranges, respectively, allowing for the investigation of spectra between 230–920 nm with a resolution of > 0.1 nm. The plasma is either vertically scanned in successive measurements and reconstructed from thin slices or entirely imaged by means of bandpass filters, see Fig. 3. Measurements were performed simulating a Martian environment with an ambient gas mainly composed of CO_2 at 7 mbar.

Assuming cylindrical symmetry of the laser-induced plasma with the symmetry axis perpendicular to the sample surface, an Abel inversion of the measured image can be performed in order to obtain the emissivity in dependence of the radial position.

3. Results

The measurements shown here were done on pressed pellets of calcium sulfate (gypsum, $CaSO_4\ 2\,H_2O$) and of the Mars regolith simulant JSC Mars-1A. The first results indicate complex spatially and temporally varying distributions of the different particles in the plasma. The distributions depend for instance on the original reservoirs of the elements, i.e. elements of the CO_2-dominated atmosphere are differently distributed than the elements of the sample. C(I) at 247 nm and O(I) at 777 nm were found in dome-like distributions with no emission coming from the center of the plasma, see Fig. 4 (middle) for C(I). Since the sample does not contain carbon, the carbon signal is purely from the atmosphere. The void in the plasma center can be the result of a reduced number density in the plasma center due to the high pressure of the ablated material, however the emissions of C(III) ions were found to be nearly spherically distributed in the plasma central region at $r < 0.5$ mm. It is possible that the strong temperature gradient from the hot center to the cold periphery enables a high-intensity C(III) emission from the center even though the carbon density is relatively low here.

4. Conclusion

First results from spatially and temporally resolved plasma imaging indicate interesting behaviours of the LIBS plasmas constituents in Martian atmospheric conditions. The spatial distributions vary in shape and size and depend for instance on the sample itself, its chemical and physical matrix, and on experimental parameters such as the focus. More experiments need to be done to better understand the characteristics of Martian LIBS plasma and to interpret the results.

References

[1] Cremers DA, Radziemski LJ. Handbook of Laser-induced Breakdown Spectroscopy. Chichester, UK: John Wiley & Sons, Ltd; 2006. ISBN 9780470092996. doi:10.1002/0470093013.

[2] Maurice S, Wiens RC, Saccoccio M, Barraclough B, Gasnault O, Forni O, et al. The ChemCam instrument suite on the Mars Science Laboratory (MSL) rover: Science objectives and mast unit description. Space Science Reviews 2012;170(1-4):95–166. doi:10.1007/s11214-012-9912-2.

[3] Wiens RC, Maurice S, Barraclough B, Saccoccio M, Barkley WC, Bell JF, et al. The ChemCam instrument suite on the Mars Science Laboratory (MSL) rover: Body unit and combined system tests. Space Science Reviews 2012;170(1-4):167–227. doi:10.1007/s11214-012-9902-4.

[4] Wiens RC, Maurice S, Perez FR. The SuperCam Remote Sensing Instrument Suite for the Mars 2020 Rover: A Preview. Spectroscopy 2017;32(5):50–5.