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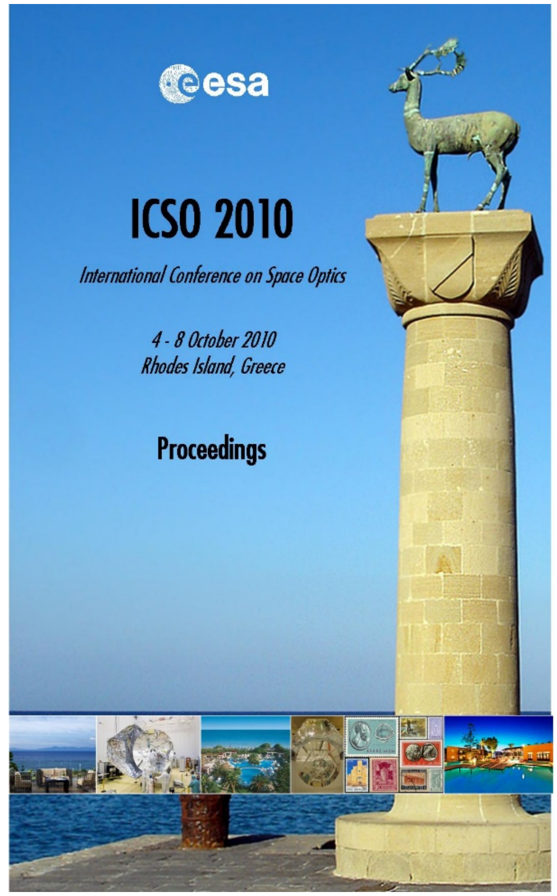

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CHEMCAM ON THE NEXT NASA MISSION TO MARS (MSL-2011): MEASURED PERFORMANCES OF THE HIGH POWER LIBS LASER BEAM

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1. INTRODUCTION

ChemCam is one of the ten instruments on the Mars Science Laboratory (also called Curiosity), a big rover being built by Jet Propulsion Laboratory (JPL), for the next NASA mission to Mars (MSL 2011).

ChemCam is a suite consisting of two remote sensing instruments: a Laser-Induced Breakdown Spectrometer (LIBS) [1] and a Remote Micro-Imager (RMI) [2]. LIBS provides elemental composition of rocks and soils, while the RMI places the LIBS analyses in their geomorphologic context.

Both instruments rely on an “autofocus” capability to automatically and precisely focus on the chosen target, located at distances from the rover comprised between 1 and 9m.

Chemcam hardware is physically divided in two separate units:

-the “Mast Unit”, built and tested in France, located on top of the rover mast,

-the “Body Unit”, built and tested in the USA, located in the rover body.

The flight model of Mast Unit has been coupled to the Body Unit, end-to-end tested, validated and calibrated [3], and is now delivered to JPL. It has been integrated on the rover (summer 2010) and tests at system level are planned in the next months. Launch of MSL is scheduled in October 2011.

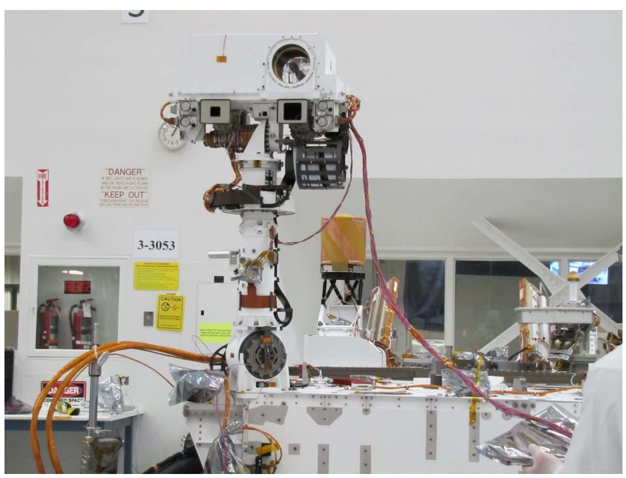

Fig. 1 view of CHEMCAM Mast Unit on the MSL Rover (Image Credit: NASA/JPL-Caltech)

Responsibilities for development, integration, testing, and future Operations and Ground data system of the complete suite are shared between USA (LANL – Principal Investigator) and France (CNES / CESR – Deputy-P.I.).

After describing the concept of ChemCam / Mast Unit, this presentation focuses on the LIBS function. It details optical characteristics, and performances measured at ambient and martian atmosphere and temperature.

2. PRESENTATION OF THE MAST UNIT

The Mast Unit (CCMU) (fig. 2) is made of two boxes:

-the OBOX (Optical Box, containing the LIBS laser, the RMI camera, the telescope and the “autofocus” devices),

-the EBOX (Electrical Box, containing all the boards necessary to provide power, control the OBOX, analyze the “autofocus” signal, and transmit data to Body Unit).

Fig. 2 CHEMCAM Mast Unit Flight Model (Image credit CNES)

The Mast Unit OBOX contains the LIBS laser source, a Galilean telescope for expanding the beam, a Cassegrain telescope (fig. 3), an objective for collect, a camera, and the "autofocus" sub-system. The LIBS laser emits bursts of short and energetic pulses. The laser beam is then focused by the primary mirror of 100mm diameter of the Cassegrain telescope to increase the optical density of the beam on the target.

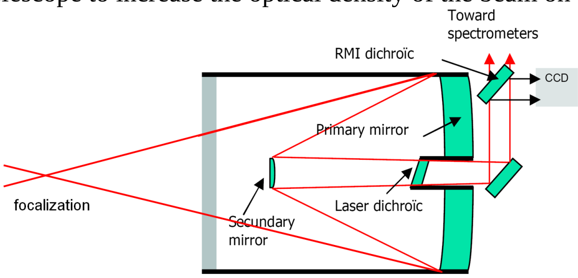

Fig. 3 Optical design of the telescope

The Mast Unit is designed to obtain a powerful pulsed diode-pumped solid-state laser source [1] with a good quality laser beam, which has to be precisely focused on the chosen Martian rock, in order to obtain a very high density of energy (irradiance > 1 GW/cm²). Thanks to this high optical intensity on the rock, this one is vaporized and plasma is created. The light emitted by this plasma is then collected by the same telescope and an objective, and sent to the Body Unit via optical fibers. Then, the optical bandwidth (240-800 nm) is splitted in three bands by a demultiplexer and provided to the three spectrometers.

The "autofocus" subsystem is made of a continuous-wave laser diode, a mechanism translating the secondary mirror, and electrical devices allowing modulation of the signal (to increase the signal to noise ratio) and synchronous detection of the reflected signal. The data are transmitted, in real-time, to the Body Unit which determines the position of the target, and focus the telescope on it.

3. MAIN REQUIREMENTS OF THE LIBS

The Energy Density requested for LIBS is > 1 GW/cm², from 1m to 9m, on the range -20°C/+20°C. The goal is to create a bright enough plasma in order to be able to collect the light and analyze it with the spectrometers.

This requirement has determined the main optical specifications of the laser:

- laser spot diameter in the range of 2,5 to 3,5 mm,
- energy of the pulses > 24mJ (laser alone),
- laser pulse of 5-8ns duration,
- beam quality $M^2 < 3$.

The transmission and collection of the telescope have been optimized for the full range of wavelength, despite the very strong optical, mechanical, and thermal constraints of this mission.

The "autofocus" precision was specified to be ±0.5% of the target distance in order to both focus the LIBS laser light properly on the target, and give focused enough RMI images. The "autofocus" sub-system was designed and characterized in order to satisfy this requirement.

Then the depth of field (DoF) for LIBS and RMI were measured to check if this precision was good enough, over the full range of distance, to do good LIBS analyzes and take good RMI images. The following focuses on the results obtained for LIBS, which is the subject of this presentation. We particularly focus on the energy density on the target for the plasma generation which is the important for LIBS analyses.

4. RESULTS

Performance tests done over the full range of applicable temperatures have proved that the requirements are fulfilled, and that a very bright plasma is generated at ambient and cold temperatures in the applicable distance range.

The ChemCam LIBS Laser source works well over -30/+30°C, and fulfills all its requirements over -20/+20°C, as required :

- laser spot diameter between 2,5 to 2,9 mm over -30/+30°C,
- energy of the pulses ≥ 20 mJ over -30/+30°C, ≥ 24mJ over -25/+20°C, and up to 35 mJ over -15/-5°C,
- laser pulse duration between 5 and 8 ns over -30/+30°C, <6 ns over -30/0°C,
- beam quality M² < 2,5 over -30/+30°C, and even ≤ 1,5 over the full range except around 10°C.

The **energy** received by the target, after focusing by the Mast Unit telescope has been measured at its best at cold (-10°C) temperature. Due to the transmission loss in the two telescopes and RWEB window (window of the box containing Mast Unit on the top of the MSL Mast), results are slightly marginal at ambient temperature.

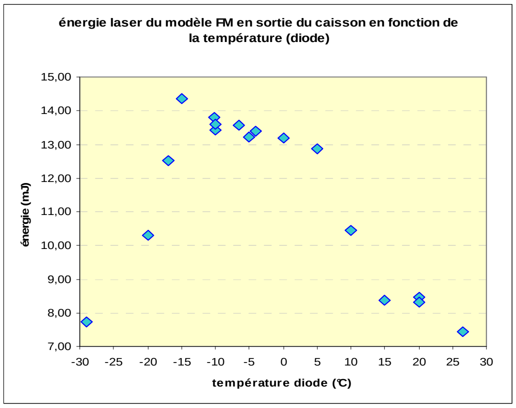

Fig. 4. Energy received by the target versus laser temperature.

The **pulse duration** has been measured at 5 ns, compliant to requirement.

The **beam shape** and the concentration of energy on the target have been simulated with ASAP software from the optical system perfectly aligned, predicting 600 µm at 7m (95% of energy).

Thanks to the good laser beam quality in the telescope entrance and particularly to the M² value (lower than 2,5 in the temperature range), the concentration is measured better than predicted, and the irradiance level on the target is good enough to obtain plasma even at long distances.

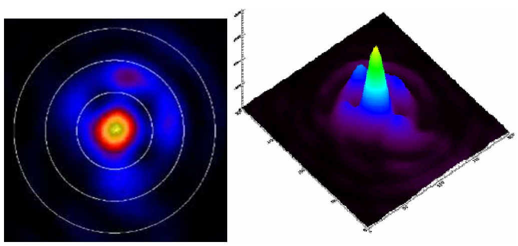

Fig. 5 : Concentration of energy measured on the target at 9 m.

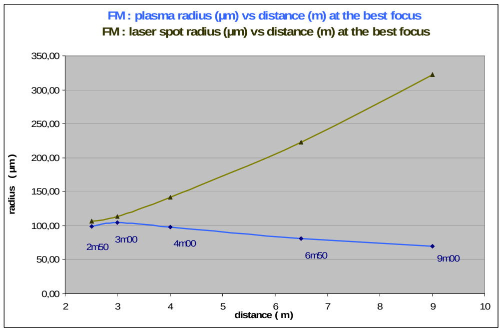

Fig. 6 : Radius of the laser spot and the plasma versus distance at the best focus.

The LIBS **Energy Density** (ED) is computed from the laser beam shape around the best focus, and plotted versus $1/d^2$ (Fig. 7), "d" is the distance to target at the best focus.

Results show that:
- at short distances, and ambient temperature, the Energy Density is limited to 3.5GW/cm² because it is impossible to get a smaller spot size than 200µm diameter (fig. 6), while concentrating the most energy inside,
- at long distances, and ambient temperature, the ED is still compliant with the requirement.
- at cold temperature, with laser diodes around -10°C, the LIBS laser provides the highest energy, the quality plasma is better and the requirement is fully respected up to 9m, with margin.

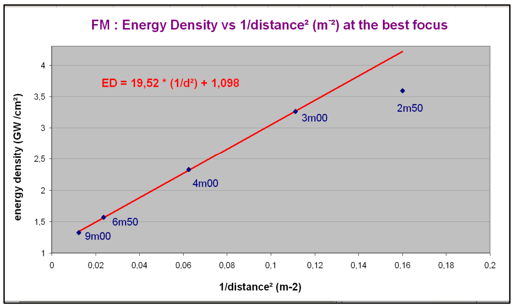

Fig. 7: Energy Density deposited on the target versus 1/distance².

The LIBS **depth of field** (DoF) has been computed with a criteria of 20% of loss of ED from the maximum value. Performance is constant between 2m50 to 9m (fig.8), giving a ½ DoF of about 11 steps of the "autofocus" mechanism.

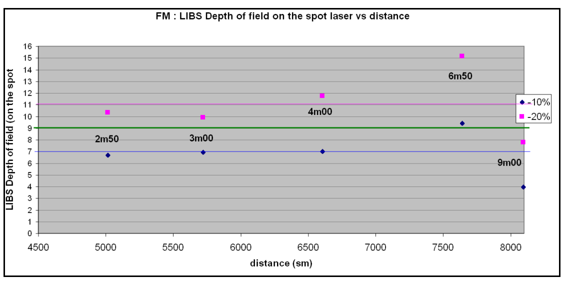

Fig. 8. ½ LIBS DoF versus distance given by Laser ED criteria

The spectral analysis of the response of the spectrometers on the three UV, VIS and VNIR spectral bands, taking a loss ratio criteria of 20% to define the DoF, gives ½ DoF constant of 15 steps of the "autofocus" mechanism (fig. 9) whatever the distance :

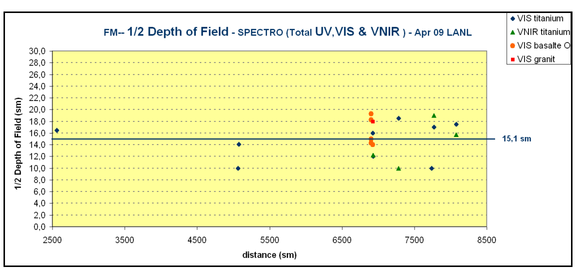

Fig. 9 : ½ LIBS DoF versus distance to target given by spectrum criteria

An **offset**, specific to the LIBS is added to the "best focus" computed by the "autofocus" self-focus sub-system, in order to optimize the focusing of the LIBS laser beam on the target. Indeed, the "autofocus" wavelength is different from the LIBS wavelength, so there is a delta between best focus positions for LIBS and "autofocus". The LIBS offset law has been determined using the spectrometers, and is depending on the distance.

The precision of focusing obtained with the "autofocus" sub-system is +/- 8 steps, 1 sigma, which is lower than the LIBS 1/2 DoF. We can then conclude that ChemCam can be precisely automatically focused, over its full range of distances (1-9 m), for LIBS analyses [4].

5. CONCLUSION

All results obtained during Mast Unit the tests conducted at CNES (France), and later at LANL (USA) at Chemcam level, have shown that the Mast Unit requirements are fulfilled.

CHEMCAM will be able to generate a plasma up to 9 m., during its mission on the Mars planet. It will allow efficient chemical analyses of the martian ground, thanks to the LIBS (Laser Induced Breakdown Spectroscopy) technique, which will be the first type of analyses of this kind made on another planet in our solar system.

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