Comparison of ChemCam, SuperCam and MarSCoDe LIBS instruments on Mars. P. Pilleri[1], Z. Chen[1,2], A Cousin[1], S. Maurice[1], O. Forni[1], R. Xin[2], ChunLai Li[2], R. Shu[3], O. Gasnault[1], R.C. Wiens[4]
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Introduction: Laser-induced breakdown spectroscopy (LIBS) has become a recognized technique for in-situ geochemical analysis in planetology over the last decade [1]. Following the legacy of the ChemCam instrument [2,3] onboard the Curiosity rover, which landed in Gale crater on Mars in 2012, two additional instruments are using this technique for Mars exploration: SuperCam onboard Perseverance [4,5], which landed in the Jezero crater in 2021, and MarSCoDe onboard Zhurong [6], which landed in 2021 in Utopia Planitia and is the first Chinese mission on Mars.

The basic principle of the LIBS analysis in these instruments is to focus an infrared laser on a target within ~7 m of the rover thus creating a plasma of ablated material. The light from the plasma is then captured by the telescope and transferred to the spectrometers for registration. Thus, all these LIBS shots translate into a spectrum in the ultraviolet (UV) violet (VIO) and near infrared (NIR) domains. ChemCam was the first to investigate the surface of Mars with this technique and has now analyzed more than 3500 rock and soil targets. Each target is sampled at several positions, constituting a “raster”, in order to observe spatial inhomogeneities. Each point of a “raster” is actually shot several times (usually 30) in order to improve the statistical significance of the collect, improve the signal to noise ratio (SNR), and differentiate surface properties (dust) and the interior of the target. The LIBS analysis is accompanied by a high-resolution remote-micro-imager observation [7], to provide context of the target that has been sampled.

The collected spectra are cleaned and calibrated by an ad-hoc pipeline. Quantification models are then applied to the spectra [8,9,10] by comparing the spectral signatures observed on Mars with a laboratory database obtained with a copy of the instrument. ChemCam has 10 calibration targets onboard the rover [7,8], with the purpose of validating the performance of the instrument along the mission, and to verify that the quantitative models give consistent results on targets of very well-known compositions.

Thanks to the lessons learned from ChemCam, SuperCam contains more LIBS calibration targets (23 in total), with the goal of validating the models on a wider range of compositions. A replica of the Shergottite calibration target on ChemCam was included on SuperCam with the goal of allowing a cross-comparison of the two instruments, and allow a comparison between the results in Gale and Jezero. For a similar goal, the MarSCoDe instrument onboard Zhurong, has 12 calibration targets and one of them is a Norite, a replica from ChemCam. The three instruments also each have a titanium target that is used mainly for wavelength calibration.

To summarize, there are now three rovers at the surface of Mars using the same LIBS technique, and their data can be compared via a reference target to ChemCam. Also, the LIBS technique being sensitive to matrix effects, each instrument has developed a laboratory database for quantitative purposes, which contains several common samples. A cross-calibration can therefore be very interesting to make the databases usable for the three different instruments. The goal of this study is to give the context of each instrument, describe their specificities (spectral range, resolution, SNR, irradiance), and compare the spectra obtained from their common calibration targets.

Results: The spectral comparison is made using the calibration targets that the three instruments have in common (Norite and Shergottite, as well as Titanium). The data processing for the spectra coming from all the instruments is very similar, and thus the comparisons have been made using the cleaned and processed spectra available on the planetary data system (PDS). Lines have been fitted using a Voigt function in order to check the signal-to-noise ratio, resolution of each spectrometer and line intensity ratios.

Spectral performance. The three instruments cover the UV, VIO and Near-IR spectral ranges. They all start at ~240 nm and extend to the near-IR up to ~850 nm (SuperCam, MarSCoDe) or 906nm (ChemCam). However, ChemCam and SuperCam have a gap between ~341 and 382 nm, while MarSCoDe spectral coverage is continuous. The spectral resolution is similar for the three instruments, with each instrument performing better in a given wavelength range. Because MarSCoDe’s operating range extends farther down, to -60 Deg C, thermal effects on the detectors can impact the wavelength stability. This will need to be assessed and corrected using the Ti spectra, as done for ChemCam.

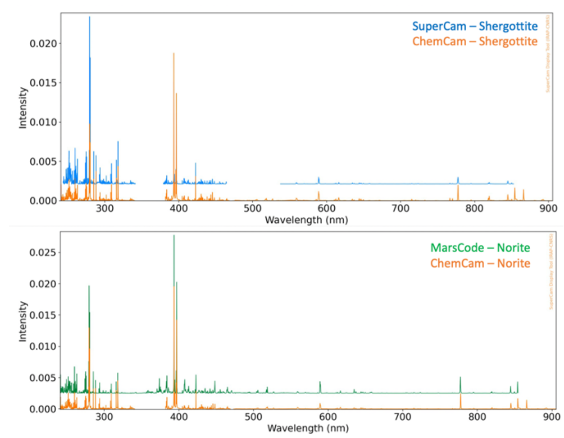
	MarsCode	SuperCam	ChemCam
Laser wavelength (nm)	1064	1064	1067
Laser Energy on target (mJ)	8-10	up to 14	10
Laser frequency (Hz)	1-3	3-10	1-10
Spectral ranges (nm)	240-850	244-341; 382-467; 535-853	240-342; 382-469; 474-906
pulse duration (ns)	4	4	<8
spot size (microns)	60-250	100-450	350-550
irradiance (GW/mm2)	6.4 at 1.6m	14 at 1.6m	~4.5 at 1.5m
resolution (UV, VIO, VNIR) (nm)	0.19, 0.31, 0.45	0.15 - 0.65	0.2 < 500 nm, 0.65>500nm
operating range (Deg C)	-60/+30	-40/+30	-30/+30

Signal To Noise Ratio. We calculated the signal to noise ratio by performing a line fitting at different wavelengths, and comparing with the standard deviation in a close-by region with no spectral lines. The SNR is very similar for the three instruments in the UV and VIO range, but ChemCam and SuperCam have better performances in the VIO range. These can be due to a number of effects, such as a different spot size, which is smaller for MarSCoDe (See table 1), the higher irradiance for SuperCam, and different focus accuracies. MarSCoDe has a variation of spot size and optical alignments as a function of the operating temperature [6], especially in the range below -20 Deg C.

Shot-to-shot stability.: In order to evaluate the shot-to-shot stability in the different instruments, we calculate the standard deviation over the mean of the total signal collected in the different spectra acquired on a given calibration target. For Norite and Shergottite, each LIBS activity consists of 30 shots (thus 30 spectra), whereas only 10 shots were performed on the Titanium target. ChemCam spectra proved to be very stable, especially in the UV and in the near-infrared. Stability is very similar in the VIO for ChemCam and SuperCam. However when using Shergottite and Norite, obtained with 30 shots, the three instruments are overall similar.

Line peak ratios. We have compared the spectra of Norite targets from ChemCam (Sol 27) and MarSCoDe (Sol 41). The presence of atomic emission was visually similar while certain inconsistencies in line ratios could be observed. The line intensities of 9 elements (Al, Si, Ti, Fe, Ca, Mg, Na, K, O) were compared (after normalization to the Ca-393.5 nm line). The normalized intensities follow the 1:1 line well with good R-squares. The ratios of normalized intensity shows no significant dependency on the wavelength so it may not be largely attributed to the general difference in instrumental responses. It is thus assumed that the difference in relative intensities was mostly induced by the difference in excitation, given the nearly identical norite materials.

Conclusions With three rovers at the surface of Mars that are each equipped with a LIBS instrument, understanding their differences in design and performance is important for a consistent comparison of their results. A complete cross-calibration of the three instruments and of the spectral database used for quantification, is needed to compare results on elemental compositions. In the long term this will allow to compare variations in the elemental composition of dust, rocks and soils in three different sites on Mars.



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References:

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