SUPERCAM RAMAN ONBOARD MARS 2020 ROVER: OVERVIEW AND TEST DATA


Introduction: The SuperCam instrument will combine various investigation techniques onboard the NASA Mars2020 rover in Jezero crater [1]: Laser Induced Breakdown Spectroscopy (LIBS), time-resolved Raman (TRR) and luminescence (TRLS) spectroscopy in addition to VISIR, a microphone and a remote micro-imager (RMI). This versatile remote-sensing instrument will provide chemical and mineralogical information from the same spot on the target at a sub-mm to mm scale. Here, we present the Raman and luminescence part of the instrument as well as Raman and luminescence spectra acquired by SuperCam during development and testing.

Instrument description: SuperCam is composed of a mast unit (MU), a body unit (BU) connected by an optical fiber, and a set of calibration targets. The mast unit at the top of the rover mast includes a laser, a telescope, an IR spectrometer and RMI and electronics. For Raman spectroscopy, the excitation source is a pulsed, frequency doubled Nd:YAG laser, operating at 532 nm with a 4 ns pulse width, 10 mJ pulse energy and 10 Hz pulse repetition rate. The laser is collimated on the target illuminating a surface of a few mm² in extent. Irradiance at the sample location ranges from 10¹⁰ to 5.10¹⁰ W m⁻². The telescope collects light within the laser footprint with a collection area ranging from ≈1.5 mm at 2 m to ≈5.2 mm at 7 m: this is the analytical footprint. Light is then transferred to the optical fiber by several optics including a soft notch filter removing 95% of the reflected laser light. In the BU, light for TRR and TRLS is directed to a transmission spectrometer thanks to an optical demultiplexer including an edge filter to remove the Rayleigh light (cutoff ≈140 cm⁻¹). The transmission spectrometer is a new compact design including diffraction gratings, an intensifier, and relay optics that focus light onto a CCD. This configuration yields a spectral resolution better than 12 cm⁻¹ for the Raman window and allows collection of luminescence emission signal from 535 to 850 nm. Wavelength calibration will be obtained from reference LIBS spectral lines, but two calibration targets were specifically designed for Raman: a diamond to assess the instrument integrity (intensity for alignment, FWHM for resolution...) and an organic target to monitor the detection of organics on Mars and possible irradiation effects on the Raman signature. Detailed description of the instrument is given by [2].

How does SuperCam’s Raman spectrometer differ from commercial instruments? SuperCam’s Raman spectrometer differs from commercial laboratory instruments in two fundamental ways. First, SuperCam remotely-senses with a telescope Raman signal at large distances (i.e. 2 to 7 m) with large laser spot sizes (i.e. a mm in diameter or greater) while commercial laboratory instruments detect Raman signal at short distances (i.e. ~ mm) with small spot sizes (i.e. ~ µm) by using a microscope. Hence, SuperCam Raman will likely probe a population of phases depending on grain size while laboratory instruments generally targets a single phase. Second, SuperCam utilizes a pulsed excitation source combined with a gated detector, while commercial laboratory instruments typically employ continuous-wave (CW) excitation sources and detector. The idea is that Raman signal (lifetime ≈10⁻⁶ s) is only produced during the excitation pulse, while other signals like luminescence (lifetime >10⁻³ s) are excited by the pulse but continue to decay after it. Using a short gate (100 ns for SuperCam) that is synchronized with the laser pulse allows efficient rejection of parasitic signals, like luminescence or daylight entering the telescope, and optimized collection of the Raman signal. TR spectroscopy further allows collection of only the luminescence signal by opening the detector gate just after the laser pulse: the Raman signal by then is absent while the luminescence is still present. Compared to CW instruments, SuperCam Raman benefits from signal intensification and filtering in the time-domain but uses considerably less excitation, hence receives less signal because of the non-continuous excitation.

Testing SuperCam Raman (TRR): SuperCam’s Raman spectrometer has been tested during several campaigns at LANL using various configurations (EQM: engineering qualification model, FM: flight model): EQM-MU/EQM-BU in 2018 and EQM-MU/FM-BU in 2019. The final FM-MU/FM-BU was tested after integration onto the rover at JPL during summer 2019 [3,4]. In general, for Raman, the number of shots is set at 100-200, the gate is set at 100 ns and the distance to target was varied from 2 to 4 m. Various mineral targets were tested: silicates, phosphates,
sulfates, carbonates and accessory phases (e.g. oxides). Most targets were used as raw single crystals but some were prepared as powder pellets. Some organics and real rocks were also tested during the campaigns.

TRR spectra are generally high-quality for phosphates, sulfates and carbonates with clear detection of internal molecular modes and lattice vibrations. Notably, (i) polymorphs can be unambiguously distinguished (e.g. calcite vs. aragonite, Fig. 1), (ii) OH/H$_2$O is clearly detected/specified in relevant phases (e.g. gypsum, hydromagnesite, Fig.2) and (iii) spectral resolution is enough to detect differences in subtle Raman shifts of main peaks due to compositional variations (e.g. Mg vs. Ca carbonates, Fig. 1). Some silicates (e.g. olivine, pyroxene, talc) yield good spectra as well (Fig. 3) with similar information, while others are challenging to analyze (e.g. some phyllosilicates). Accessory phases like opaque minerals are non detectable. For these and other challenging phases, it is mostly due to the high value of their optical absorption coefficient that prevents volumetric analysis and/or to their poor Raman efficiency (even with CW lab instruments!). Preliminary tests with real rocks show that very fine grained rocks will be challenging for Raman analysis while coarse grained rocks will be more favorable.

**Analyzing luminescence (TRLs):** SuperCam’s time-resolution properties efficiently removes most mineral luminescence when acquiring Raman spectra. On the other hand, SuperCam can efficiently remove Raman signal in order to isolate luminescence signal. For example, luminescence may be used to detect emission centers at trace concentrations like Mn$^{2+}$ or rare-earth elements (REEs) in various mineral matrices [5]. An example is depicted for REE detection at 10s ppm level in zircon in Fig.4.

**Synergy with other instruments:** LIBS will be used first to remove dust on the target’s surface as dust is detrimental for Raman and IR analysis. Owing to the much larger analytical footprint of Raman compared to LIBS spots, we do not anticipate any Raman spectral artefacts due to the prior LIBS ablation [6].

**Conclusion:** SuperCam Raman performs very well with many mineral phases of high interest for Jezero crater (e.g. carbonates, sulfates). Alternatively, some minerals/rocks are inherently hard to detect with Raman. SuperCam TRLS is an interesting new tool as it can efficiently detect and identify trace elements like REEs in minerals.

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**Fig. 1** Raman spectra of carbonates: aragonite (blue), dolomite (red) and calcite (black). Note the difference in lattice vibrations for calcite vs. aragonite and difference in peak positions for calcite vs. dolomite.

**Fig. 2** Raman spectra of hydromagnesite (hydrated Mg-carbonate, black) and gypsum (sulfate, red). Note the hydration OH/H$_2$O bands.

**Fig. 3** Raman spectra of some silicates: quartz (red), olivine (blue) and diopside (black).

**Fig. 4** Raman spectrum of zircon (black) and luminescence emission spectrum of zircon (red). Note that several REE trace elements are identified.