THE SUPERCAM REMOTE RAMAN SPECTROMETER FOR MARS 2020

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Overview: The Mars 2020 Science Definition Team developed criteria for advanced instrumentation for the next NASA rover. One important criterion is to provide mineral compositions at remote distances [1]. Hence, the SuperCam instrument that was selected provides two remote mineralogy techniques: passive visible and infrared (VISIR) reflectance spectroscopy and remote Raman spectroscopy. These are in addition to providing co-bore-sighted remote elemental compositions, color images, and acoustic spectra (sounds) [2]. SuperCam's remote Raman spectroscopy complements the rover's in-situ Raman experiment, SHERLOC (see below; [3]), and RLS on ExoMars, as the first Raman spectrometers to be built for another planet. Here we provide an in-depth description of the SuperCam Raman spectrometer and its operation.

Architecture: Remote observations provide far greater flexibility with which to observe targets from a rover platform. Remote Raman spectroscopy requires the use of a telescope, a pulsed laser, and a time-gated, intensified detector to provide sufficient signal to noise. We use the same overall ChemCam architecture, using a 110 mm collection aperture, a mast-to-body optical fiber, and a spectrometer in the rover body, frequency doubling the Nd:YAG laser to provide a green 532 nm beam. We use a transmission spectrometer equipped with an intensifier with adjustable gain up to 50k. The intensified signal is projected in the form of multiple spectral traces onto a single CCD to maximize the product of spectral range and resolution (Figs. 1, 2). A high-voltage power supply (HVPS) capable of operating in the Mars environment has been miniaturized, so that it mounts directly beneath the spectrometer (Fig. 1).

Capabilities:

Mineral Detections: SuperCam will identify carbonates, sulfates, phosphates, ices, olivine, and quartz at 1% abundance, and plagioclase, feldspars, phyllosilicates, and some organics and metal oxides at 5% abundances, and pyroxenes at 10%, all up to 7 m distance using either VISIR or Raman. The two techniques are highly complementary; Raman will clearly be the best technique for plagioclase feldspars, quartz, olivine, rutile, and organics. Pure sulfates and carbonates should be observable by Raman to distances of tens of meters. Laboratory measurements are being used in advance of the flight instrument to validate the expected instrument performance [5, 6].

Raman Spectral Resolution: To achieve the above detections there are three criteria where spectral resolution is important: a) determining the absolute position of a peak, e.g., to distinguish whether a spectral peak belongs to dolomite from calcite. For this one needs to precisely know the laser wavelength and the spectrometer wavelength calibration as well as to have reasonable resolution; b) to identify a mineral by resolving two of its closely-spaced peaks. Examples of this are olivine or albite whose twin peaks are generally characteristic of their spectra; and c) to identify the presence of two or more minerals in the same spectrum by resolving their respective peaks. An example is quartz and albite, which often occur together. A FWHM of 12 cm^{-1} validated on a naturally narrow emission line meets all of the above needs. There are other ways of specifying resolution, such as the pixel spread or the theoretical resolution of a system. For example, the 12 cm^{-1} FWHM criterion is better than examples labeled in [4] as "4 cm^{-1}", the highest resolution considered for planetary science in that feasibility study.

Spectrometer Improvements: The SuperCam Raman spectrometer was originally proposed with two spectral traces filling two different spatial regions across the CCD. The separate traces are the result of a dichroic beam splitter that directs light to two side-by-side gratings (Fig. 1), one of which is slightly tilted relative to the other to achieve separation between traces. To provide margin against the above resolution requirement, the current design converts one of these two gratings into a compound grating, providing three spectral traces (Fig. 2). The pixel resolution is now < 2.5 cm^{-1} and the FWHM resolution is < 9 cm^{-1} at all wavelengths. The design also allows the aperture slit width to be increased from 20 to 30 µm while still achieving this higher resolution. Along with other improvements to the system, this achieves 60% higher transmission (Fig. 2).

Another improvement is the construction of an improved notch filter. The system actually uses two such filters, one near the telescope to remove >96% of the reflected green laser beam, avoiding induced Raman signal from the 6 m silica mast-to-body optical fiber. A second filter resides near the spectrometer to remove any remaining 532 nm laser light. The initial telescope filter, used in the development unit [5], did not meet the required 90% transmission at 150 cm^{-1}, so a second design is being procured.

A second system-wide improvement is the optimization of the laser and spectrometer footprints. The green laser beam is projected to the target from a mirror at the front center of the telescope, avoiding parallax [1]. Alignment is still challenging, as the focused telescope field of view for the Raman spectrometer is only ~0.8 mrad. The laser beam diameter must be large enough as it exits the instrument that it does not burn dust that may deposit on the RWEB window, resulting in obscuration. This is a precaution, as MAHLI images of the ChemCam RWEB window have shown it to be exceptionally clear

of dust throughout the mission. The SuperCam development unit [5] uses an 8 mm diameter green beam. The flight unit will likely use a ~5 mm beam, resulting in a factor of nearly 3x increase in signal at distances closer than ~7 m. The 5 mm beam appears to still have a factor of ~10x margin relative to damaging the window. Experience with ChemCam suggests that nearby observations (e.g., closer than ~7 m), which stand to gain from this modification, are made more frequently than those at greater distance due to the greater detail observed close up in Navcam and Mastcam images used for targeting.

Comparison with SHERLOC: The two Mars-2020 Raman spectrometers are fundamentally different. While SuperCam avoids most fluorescence interferences to the Raman signal by time gating, SHERLOC avoids these interferences by operating in the deep UV where fluorescence does not occur. SHERLOC uses a 248.6 nm CW laser beam focused to 50 µm to map over a ~7x7 mm area of selected samples. Its spectral window starts at 810 cm^{-1}, missing most silicate structural signatures, but it is highly sensitive to organics (sub-ppm for aromatics, < 100 ppm for aliphatics) [3]. In this way, SuperCam focuses on general mineral detection with some organic capabilities, while SHERLOC focuses on organics with some mineral capabilities. The two instruments are thus highly complementary.

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References: [1] J.F. Mustard et al. (2013) Report of the Mars 2020 Science Definition Team, http://mars.nasa.gov/mars2020/files/mars2020/SDT-Report%20Finalv6.pdf; [2] R.C. Wiens et al. (2017) The SuperCam remote sensing instrument suite for the Mars 2020 rover mission: A preview. *Spectroscopy*, in press; [3] L. Beegle et al. (2015) SHERLOC, IEEE, doi: 10.1109/ AERO. 2015.7119105; [4] Villar & Edwards (2005) Vib. Spec. 39, 88; [5] A. Ollila et al. (2017) this meeting; [6] R.C. Wiens et al. (2017) Signal strengths of common minerals using pulsed laser Raman spectroscopy. Spectrochim. Acta A, submitted.

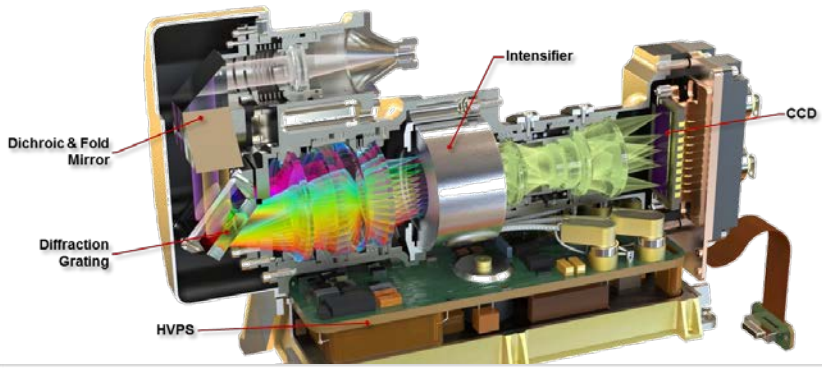

Fig. 1. Cut-away view of the SuperCam Raman spectrometer. Light enters (top) from an optical fiber bundle over which an aperture slit is mounted. The dichroic (left) splits light into two traces. The grating is actually two side-by side gratings, one of which is compound. For scale, the intensifier aperture is 18 mm diameter.

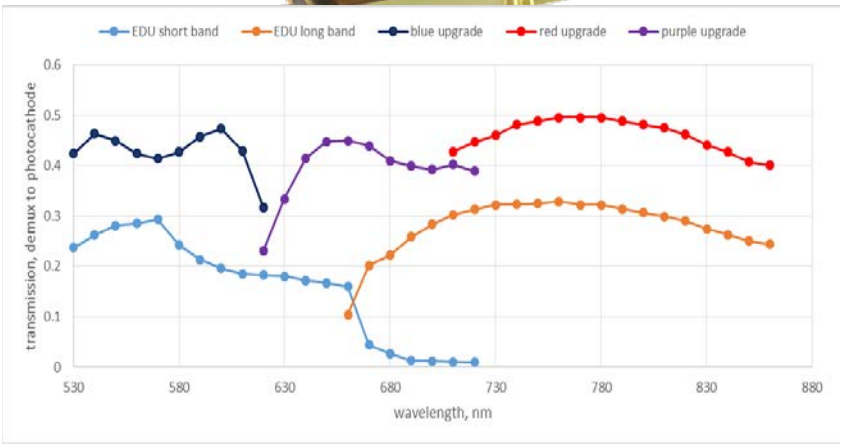

Fig. 2. Comparison of optical transmission of the previous 2-trace design (lower curves) to the current 3-trace design (upper curves), implemented with a compound grating which achieves higher resolution while nearly doubling the transmission. The transition between blue and purple traces occurs at 598-618 nm (2100-2600 cm^{-1}). The second Raman region extends to 4900 cm^{-1}. The red trace (upper right), to 853 nm, is used exclusively for fluorescence, LIBS, and passive reflectance spectroscopy.