THE SUPERCAM REMOTE SENSING SUITE FOR MARS 2020: CO-ALIGNED LIBS, RAMAN, AND NEAR-IR SPECTROSCOPIES, AND COLOR MICRO-IMAGING.

R.C. Wiens[1] S. Maurice[2], J.R. Johnson[3], S.M. Clegg[1], S. Sharma[4], F. Rull[5], F. Montmessin[6], R.B. Anderson[7], O. Beyssac[8], L. Bonal[9], L. Deflores[10], G. Dromart[11], W. Fischer[12], O. Forni[2], O. Gasnault[2], J. Grotzinger[12], N. Mangold[13], J. Martinez-Frias[14], S. McLennan[15], K. McCabe[1], P. Cais[16], T.E. Nelson[1], S.M. Angel[17], P. Beck[9], K. Benzerara[8], S. Bernard[8], B. Bousquet[16], N. Bridges[3], E. Cloutis[18] C. Fabre[19], T. Fouchet[20], O. Grasset[13], N. Lanza[1], J. Lasue[2], S. Le Mouelic[13], R. Leveille[21], E. Lewin[9], T. McConnochie[22], N. Melikechi[23], P.-Y. Meslin[2], A. Misra[4], G. Montagnac[11], H. Newsom[24], A. Ollila[24], P. Pinet[2], F. Poulet[25], V. Sautter[26], P. Sobron[27] [1]LANL (rwiens@lanl.gov); [2]IRAP, Toulouse; [3]APL/JHU; [4]U. Hawaii; [5]U. Valladolid; [6]LATMOS, Paris; [7]USGS, Flagstaff; [8]IMPMC, Paris; [9]IPAG, Grenoble; [10]JPL; [11]ENS, Lyon; [12]Caltech; [13]LPG, Nantes; [14]CSIC-UCM, Madrid; [15]SUNY Stony Brook; [16]U. Bordeaux; [17]U. S. Carolina; [18]U. Winnipeg; [19]GeoRessources, Vandoeuvre; [20]Observatoire de Paris, Meudon; [21]CSA; [22]GSFC; [23]Delaware State U.; [24]UNM; [25]IAS, Orsay; [26]MNHN, Paris; [27]SETI

Summary: Remote microscale characterization of the mineralogy and elemental chemistry of the Mars surface, along with the search for extant organic materials, are fundamental investigations that lay the groundwork for all types of Mars geochemistry and astrobiology investigations. SuperCam on Mars 2020 is a suite of four instruments that provide these critical observations via Laser Induced Breakdown Spectroscopy (LIBS), Raman spectroscopy, visible and near-infrared spectroscopy (VISIR), and high resolution color imaging, all co-aligned and at micro-radian angular resolution. A key observational aspect is the laser cleaning of the rock surfaces, which provides a clear view of the target for all four techniques. SuperCam's implementation relies heavily on the successful ChemCam instrument on MSL.

Investigation Goals: SuperCam has eight goals that map into the Mars 2020 mission objectives:

Rock Identification: SuperCam will identify individual minerals via Raman and VISIR spectroscopy, as well as LIBS major elements present in rocks. Quantification of the chemistry enables a more precise determination of the overall composition as a complement to mineralogy. Conversely, the specific capability of Raman and VISIR to identify primary and secondary minerals (sulphates, carbonates, hydrous silicates, etc.) strongly constrains the LIBS bulk chemistry.

Sedimentary Stratigraphy and Facies / Hydrothermal Characterization: Color images allow a detailed analysis of the facies of sediments, thus providing an identification of depositional features (ripples, cross-bedding, lamination) as well as diagenetic features (nodules, veins, etc.). The LIBS chemistry (including major and relevant minor/trace elements) and the mineralogy obtained by Raman and VISIR will enable us to understand the provenance of the sediments and to interpret any later modification by aqueous processes (e.g., diagenesis or weathering).

Organics and Bio-signatures: LIBS data allow the identification of elements, such as C, H, N, O, P and S. The coupling with Raman is powerful because this technique can determine a large number of organic molecules from the variety of molecular vibrations between C, N, O, and H.

Volatiles (H & Halogens): Among the volatiles detectable by LIBS, H is key to determining aqueous alteration, not only in primary hydrous phases but also as cements or adsorbed phases. S, Cl, F, P, Li are also important LIBS elements; Raman and VISIR will place these in the context of alteration minerals.

Context Morphology and Texture: High resolution color images provide morphological context and will provide a visual approach to oxidation states of layers relevant for aqueous processes.

Coatings and Varnishes: LIBS is uniquely capable of non-contact coating identification by detecting minor elements such as Mn, especially by providing depth profiles at the scale of the coating thickness.

Regolith Characterization: SuperCam will address soil diversity and will characterize the soil potential for biosignature preservation. Coupling of VISIR with LIBS H analysis will help understand the widespread hydration at Mars' surface. LIBS detection of hazardous elements (As, Pb, etc.) in dust will provide important data for human exploration.

Atmospheric Characterization: The CO, O_2, and O_3 relative abundances and distributions are controlled in large part by odd hydrogen radicals sourced from pho-

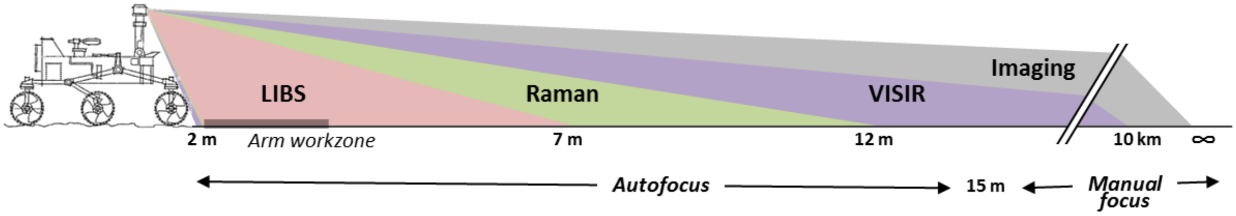

Fig. 1. SuperCam operates over a large range of distances. All investigations can be performed as close as 1.4 m.

tolyzed water vapor. They have been observed individually but have never before been observed simultaneously in the same atmospheric column, as planned by SuperCam. Atmospheric CO, O_2, and H_2O are all potentially valuable for ISRU; O_2 variability and local-scale H_2O temporal variability are poorly known.

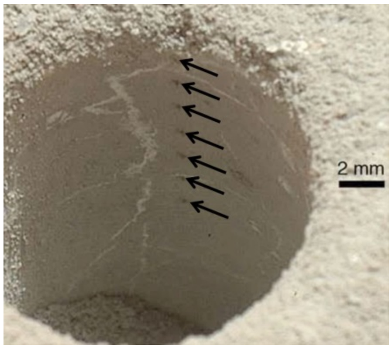

Fig. 2. ChemCam laser pits in John Klein hole. SuperCam will document Mars 2020 cache cores and their holes.

Capabilities: SuperCam provides four nested and co-aligned remote observation techniques that cover a large range of distances from 1.4 m to infinity (Fig. 1). Mission goals are traceable through the eight investigation goals, to the specific requirements for the four techniques. Some of the critical capabilities are given below:

LIBS: SuperCam LIBS capabilities essentially mirror those of ChemCam's, providing rapid, high-precision elemental compositions on analysis spots ≤0.5 mm diameter to 7 m distance, permitting depth profiles and chemostratigraphy. Precise targeting also enables arm work-volume support (Fig. 2).

Raman and Time-Resolved Fluorescence Spectroscopy: SuperCam will use a pulsed, frequency-doubled laser beam to provide Raman signals at distances to 12 m for Raman-dark (i.e., olivine) minerals, and to greater distances for Raman bright minerals (including carbonates and sulfates). It will cover 150-4400 cm^{-1} at a resolution requirement of 10 cm^{-1}. Spatial resolution is < 0.8 mrad, and a scan mode is supported. Time-gating of the detector to < 100 ns facilitates time-resolved laser-induced fluorescence from 534-850 nm. Organic and biological molecules produce fluorescence both with UV and visible laser excitation with very short lifetimes (< 1 ns to 200 ns). Our time-resolved instrument will be able to distinguish short-lived organic fluorescence from that of longer-lived (µs-ms) minerals and rocks on Mars, thus identifying targets that have biological molecules embedded in them. In the absence of biological materials, SuperCam Raman will not have interference from short-lived fluorescence backgrounds.

VISIR: ChemCam currently carries out reflectance spectroscopy investigations in the range of 0.4-0.85 µm with a resolution of 0.65 nm. SuperCam will add the very important near-IR range over 1.3-2.6 µm (resolution: 0.02 µm), providing identification of a large range of minerals: oxides and hydroxides, ortho- and chain silicates, sheet silicates, mono- and polyhydrated sulfates, and carbonates. This range will also be used for atmospheric observations.

Remote Micro-Imaging: On MSL, ChemCam's RMI is the highest resolution remote imager on the rover, with a field of view of 20 mrad and single pixel FOV of 19 µrad. SuperCam's RMI will provide similar resolution and field of view but this time in RGB color, allowing much better interpretation of fine-scale textures, especially, e.g., in terms of Fe oxidation state.

Synergy: Co-Aligned Analyses, Dust Removal: A very important aspect of SuperCam is the ability to make all four types of measurements almost simultaneously, e.g., without re-pointing the instrument. The mast mounting assures a high volume of data, comparable to the > 4,000 observation points characterized by ChemCam in the first two years. The imaging, Raman, and VISIR will benefit from the dust removal provided by the LIBS plasma (Fig. 3) to 7 m distance.

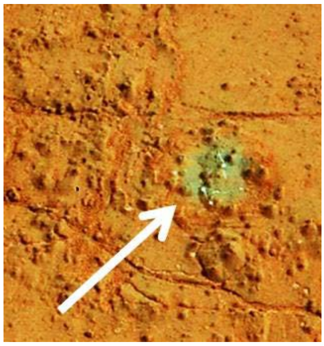

Fig. 3. LIBS dust removal reveals gray mudstones at Gale.

Instrument Description: Fig. 4 shows a block diagram of the instrument. SuperCam consists of two major sub-sections connected by electrical cables and an optical fiber. The Mast Unit (MU), which resides on the rover's mast, contains the laser, associated electronics, telescope, imager, and the infrared spectrometer. SuperCam uses a mechanical switch to direct the laser beam in one of two pathways,

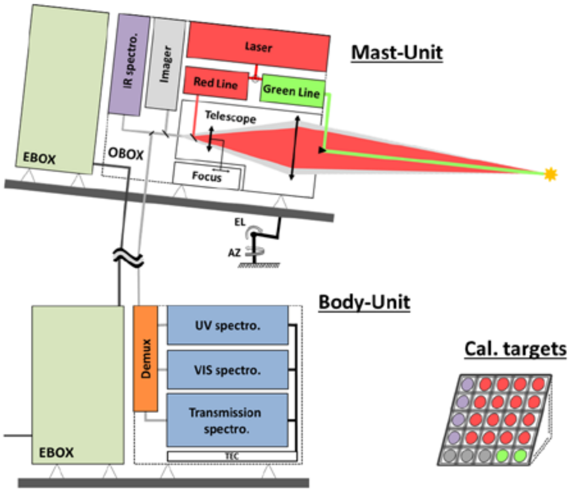

Fig. 4. SuperCam block diagram.

one through the 110 mm diameter Schmidt-Cassegrain telescope to provide the focused beam for LIBS (“red line” = 5-14 mJ @ 1064 nm), and another through a frequency doubler to provide the “green line” (2-18 mJ @ 532 nm) for Raman spectroscopy.

The IR spectrometer is an independent device, linked to the telescope objective by a short optical fiber. A radio-frequency signal drives a transducer which is attached to the side of an Acousto-Optical Tunable Filter (AOTF). Thus, for each frequency of the piezo, a single wavelength is selected and scattered by ±4°. The main beam is rejected, while both polarizations are registered by two HgCdTe (MCT) photodiodes and summed. These MCTs are packaged with a triple-stage thermo-electric cooler. The unit can complete a spectral scan within several seconds. The IR field of view is < 0.8 mrad, and it can be scanned in azimuth.

The Body Unit (BU) resides in the rover body and receives the spectral signal from the MU via a 6 m optical fiber (Fig. 4). To accommodate the Raman signal, one of the three ChemCam spectrometers is replaced with a transmission spectrometer that is used for all three spectroscopy techniques: it is used as the longer-wavelength LIBS spectrometer, as the Raman spectrometer, and as the visible range of the reflectance spectroscopy. This unit uses an intensifier to amplify and gate the light from the LIBS and Raman signals. A long gate time will be used for passive spectroscopy.

Fig. 5 shows the overall appearance of the SuperCam Mast Unit and Body Unit.

Development and Teaming Approach: The SuperCam team is based on the long-term relationship between IRAP/CNES and LANL/NASA developed over the last 15 years. PI & DPI Wiens and Maurice lead the science team. Development responsibilities are summarized in the accompanying table. Significant contributions by CNES, and a smaller contribution by the Spanish Space Agency results in Phase A-D cost to NASA under $20M. The French team provides the complete Mast Unit. F. Rull leads a Spanish contribution for assembly, testing, and delivery of the onboard calibration targets. Technical expertise draws very heavily on ChemCam personnel at IRAP and LANL. Expertise for the stand-off Raman spectroscopy comes from joint U. Hawaii (Sharma, Misra) and LANL (Clegg, Wiens) developments through NASA PIDDP, MIDP, New Frontiers SAGE Phase A, and internal funding of several $M. The IR spectrometer draws its heritage from SPICAM on Venus Express. The color CMOS imager is a new development by CNES for missions that will precede Mars 2020. All parts of the instrument are at TRL 6-9 except the imager and the Raman spectrometer, both of which are scheduled to complete environmental testing within the next six months, largely on independent programs.

Table 1. SuperCam Project Responsibilities. For shared responsibilities, bold indicates a dominant role.

	US	FR	SP
Project Management	**X**	X	
Integration & Test	**X**	X	
Post-delivery Support	**X**	X	
Laser		X	
Telescope		X	
RMI Camera		X	
IR Spectrometer		X	
Flight Software, Mast Unit		X	
Ground Support Eq., MU	X	X	
LIBS Spectrometers	X		
Transmission Spectrometer	X		
Flight Software, Body Unit	X		
Ground Support Eq., BU	X		
Calibration	X	X	**X**
Data Analysis Software	X	X	
Operations	**X**	**X**	X

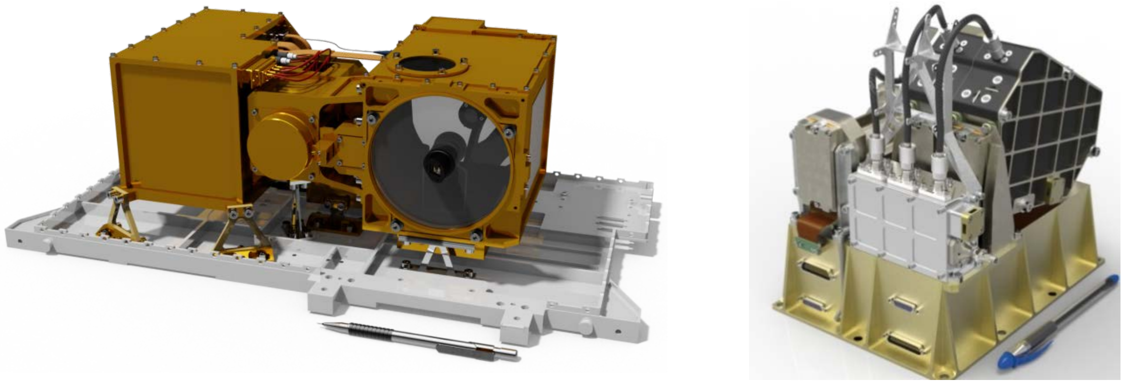

Fig. 5. CAD model renderings of the SuperCam Mast Unit (5.8 kg) and Body Unit (4.2 kg). The MU is shown on the MSL flight-version RSM camera mounting surface. Masses are given with contingencies.