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THE SUPERCAM INFRARED INSTRUMENT ON THE NASA MARS2020 MISSION
Performance and qualification results

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ABSTRACT

In July 2020, NASA will launch the Mars2020 mission. This mission, very similar to the Mars Science Laboratory and its rover Curiosity, consists in landing an instrumented rover on the Martian surface in order to characterize the geology and history of a new landing site on Mars, investigate Mars habitability, seek potential biosignatures, cache samples for an eventual return to Earth, and demonstrate in-situ production of oxygen needed for human exploration.
The rover will carry several different instruments to perform field analyses in biology, climatology, mineralogy, geology and geochemistry. Among this payload, the SuperCam instrument, an improved new generation of the ChemCam instrument on Curiosity, has been developed for remote microscale characterization of the mineralogy and elemental chemistry of the Mars surface, along with the search for extant organic materials. In addition to the elemental characterization offered by Laser-Induced Breakdown Spectroscopy (LIBS), a new remote Raman spectroscopy analysis and an infrared spectrometer have been added for a complete mineralogical and chemical characterization of the samples. A context color imaging capability is also implemented to place the analyzed samples in their geological context.

SuperCam consists of three units. The "Body Unit" built by the LANL (Los Alamos National Laboratories) in the US, the "Mast Unit" built by a French consortium of 5 laboratories (IRAP as leader, LESIA, LATMOS, IAS, and LAB) funded by the French Space Agency (CNES), and a "Calibration Target Unit" under the responsibility of the University of Valladolid in Spain.

A very compact IRS (Infrared Spectrometer) is part of the SuperCam-MU payload. The IRS concept is based on the spectral selection by an Acousto-Optic Tunable Filter (AOTF) in the 1.3-2.6 µm range with a spectral resolution better than 30 wavenumbers. The AOTF is driven by radio frequencies injected in a transducer mounted directly on a birefringent crystal. This coupling creates acoustic waves in the crystal that behave like a Bragg grating. The incident light is then diffracted in two orders (e-ray and o-ray) at the same wavelength following a so-called tuning relation law (relation between diffracted wavelength and injected radio frequency). Each diffracted order is focused on a photodiode. A complete spectrum is obtained after the scan of all individual wavelengths.

The IRS is built by LESIA and LATMOS, two French laboratories located in Paris area.

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After intensive performance and qualification tests as well as a calibration on a flight-representative model, the team has built the flight model. The qualification results and the performances of the instrument are presented.

Keywords: SuperCam, Mars2020, Infrared spectrometer

1. INTRODUCTION

The SuperCam instrument represents advancement from the design of ChemCam on MSL-Curiosity [1]. This new package is capable of four different remote-sensing techniques. In addition to the existing LIBS (Laser Induced Breakdown Spectroscopy) elemental analysis capabilities, a new Raman and time-resolved fluorescence spectroscopic analysis is implemented [3], as well as an Infrared passive Spectrometer (IRS) [4]. Both of these techniques add mineralogical capabilities as well as potential organic detection. For context imaging, an improvement of the Remote Micro Imager (RMI) is provided by a new color detector [5]. A microphone (SCM) has been added to record LIBS impacts, wind and rover sounds on the Martian surface.

The instrument suite and the science goal are described in details in [8]. An overview is given in this section.

SuperCam consists of three separate major units: Body Unit, Mast Unit and Calibration Targets (Figure 1).

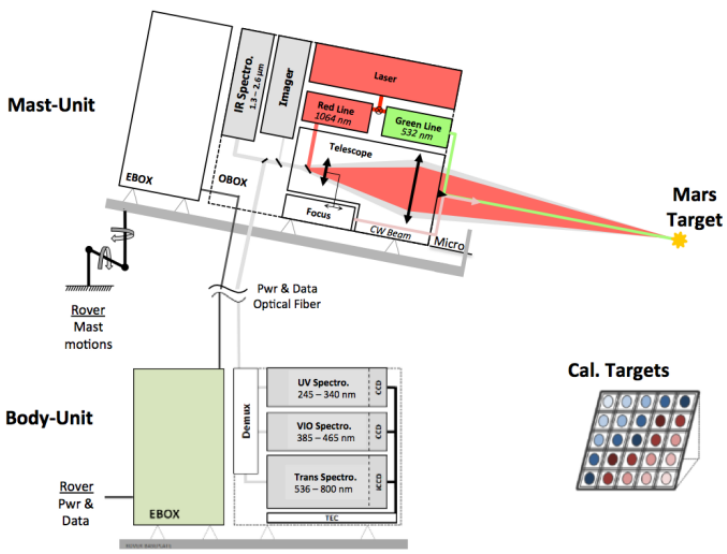

Figure 1: The SuperCam Instrument block diagram

The Mast Unit (SCMU), provided by IRAP, France and funded by CNES, consists of a telescope with a focusing stage, a "red" or "green" pulsed laser and its associated electronics, an infrared spectrometer, a color CMOS micro-imager, and the microphone (Figure **2**)

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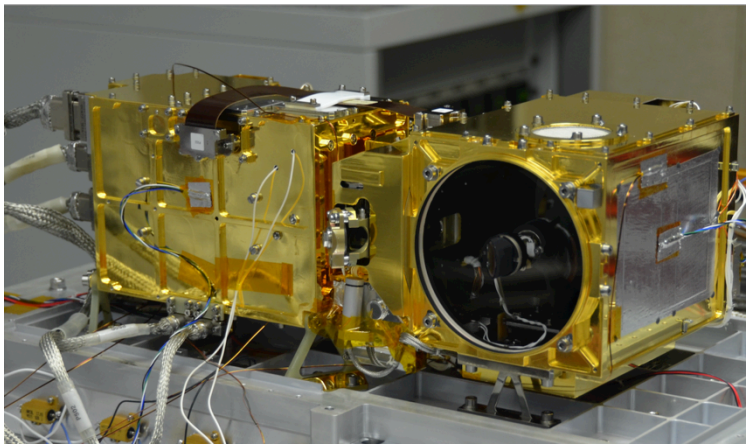

Figure 2: SCMU, EQM model

The Body Unit (SCBU), provided by LANL, USA, consists of three spectrometers covering the UV, violet, and visible and near-infrared (VNIR) ranges needed for LIBS. The UV and violet spectrometers are Czerny-Turner units identical to ChemCam. The VNIR spectrometer uses a transmission grating and an intensifier so that it can be used for remote pulsed-laser Raman spectroscopy as well as LIBS and passive reflectance spectroscopy. The intensifier allows rapid time gating needed to remove the background light so that the weak Raman emission signals can be observed, and enables time-resolved florescence studies.

A fiber optic cable, and signal and power cables, provided by JPL, connects SCBU and SCMU.

A set of calibration targets (SCCT), provided by UVa, Spain, will enable periodic calibration of the instrument.

The three units are independent mechanically, simplifying interface controls as well as development overseas, under the leadership of LANL.

The SuperCam suite of techniques supports all Mission Science objectives with the following instrument science goals [2]: 1- rock identification, 2- sediment stratigraphy, 3- organics and biosignatures, 4- volatiles, 5- morphology, 6- coatings and varnishes, 7- regolith characterization, 8- atmospheric characterization.

Synergy between the four techniques is key. Because they are co-boresighted, multiple types of measurements can be made rapidly on the same sample, providing a multi-dimensional analysis.

1.1 The LIBS spectroscopy

The LIBS benefits from six years of ChemCam operation on the Martian surface. This technique uses powerful laser pulses [6], focused on a small spot on target rock and soil samples within 7 m of the rover to ablate atoms and ions in electronically excited states, from which they decay, producing illuminated plasma. The plasma light is collected by a telescope, and focused onto the end of an optical fiber. The fiber carries the light to a demultiplexer and three spectrographs that record the spectrum over a range from 240 – 850 nm (Figure **3**). The spectra yield emission lines of elements present in the samples. Typical rock and soil analyses yield detectable quantities of Na, Mg, Al, Si, Ca, K, Ti, Mn, Fe, H, C, O, Li, Sr and Ba. Other elements that may be observed in soils and rocks include F, Cl, S, N, P, B, Ni, Zn, Cu and Rb.

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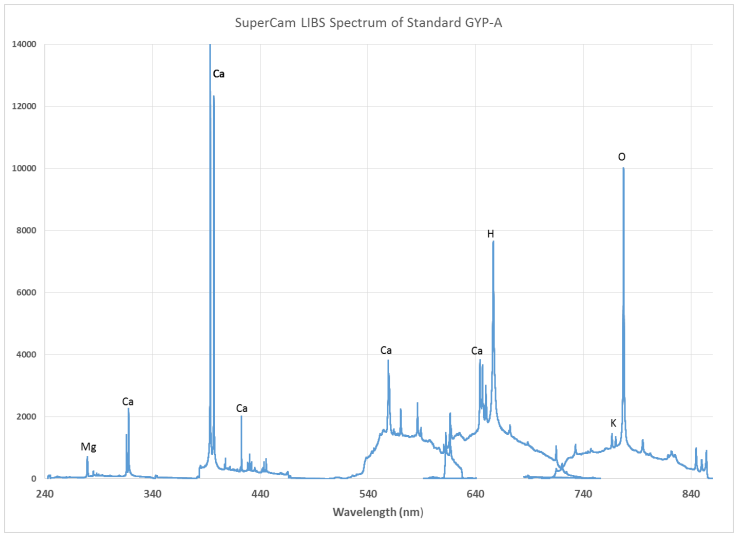

Figure 3: LIBS spectrum of GYP-A

1.2 The Raman and fluorescence spectroscopy

Standoff Raman spectroscopy provides point detection of many minerals and potential detection of different organic compounds if they exist on Mars [3]. To perform Raman spectroscopy, the laser beam is frequency doubled and is directed towards the target in a 532 nm pulsed beam of low dispersion. The target is thus illuminated at lower power density than LIBS, such that the molecules at the surface are vibrationally excited, resulting in scattered light that is modulated by the vibrational frequency of the material. This "Raman" scattered light can be detected if the much stronger Rayleigh-scattered light at the laser wavelength is blocked. Like LIBS, the telescope collects the Raman signal; it is transferred via a fiber cable to a transmission spectrometer in the rover body. The signal is intensified and recorded. The intensifier allows the exposure to be gated to a very short duration, removing background ambient light. Time-resolved fluorescence can also be recorded. Organic and biological molecules produce fluorescence both with UV and visible laser excitation with very short lifetimes (< 1 ns to 200 ns). SuperCam 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.
Figure **4** shows a Raman spectrum measured with the EQM on a rhodonite rock.

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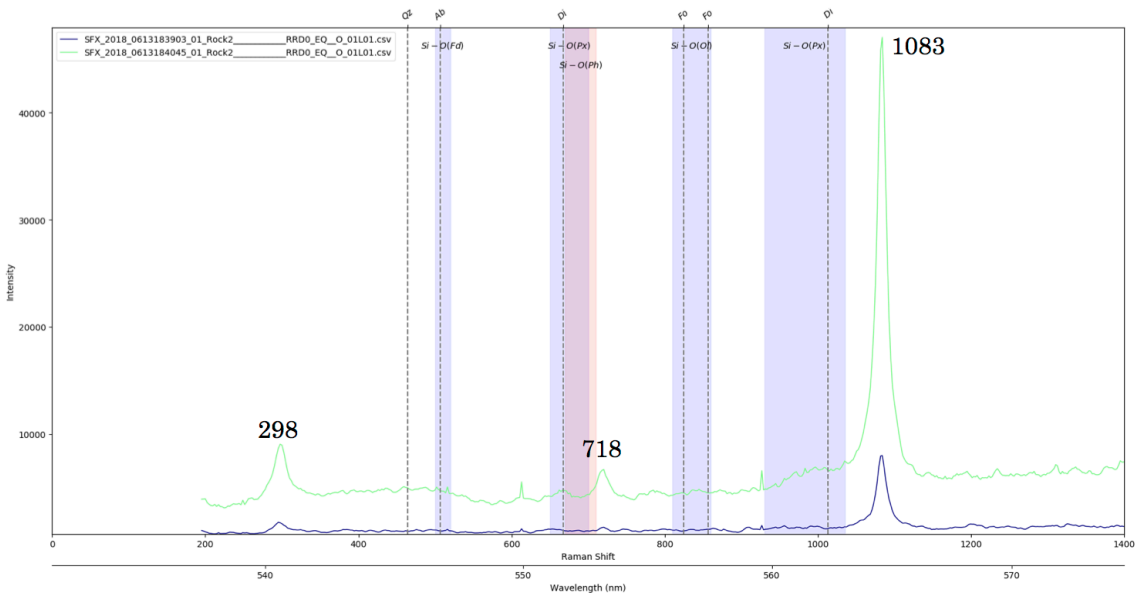

Figure 4: Raman spectrum of a rhodinite rock measured with the EQM

1.3 The visible and infra-red spectroscopy

VISIR passive spectroscopy (Figure **5**) has demonstrated its powerful capability in the detection and identification of mineral phases through characteristic absorption features related to vibrational stretching and/or bending of characteristic molecular bounds. [4] The SuperCam wavelength range (0.4–0.85 µm, 1.3–2.6 µm) provides easy identification of most minerals to be found in the Mars geological record:

- Oxides and hydroxides;
- Ortho- and chain silicates;
- Sheet silicates (phyllosilicates, smectite);
- Sulfates (mono- and polyhydrated);
- Carbonates.

It might provide a tool to identify complex organic compounds from absorptions at 1.7 and 2.3-2.5 µm.
For atmospheric measurements, SuperCam records CO_2, CO, H_2O, O_2 (IR and 700-850 nm) and O_3 (UV). The full spectral range is used to measure scattered light diagnostic of aerosol size distribution, composition, and opacity.

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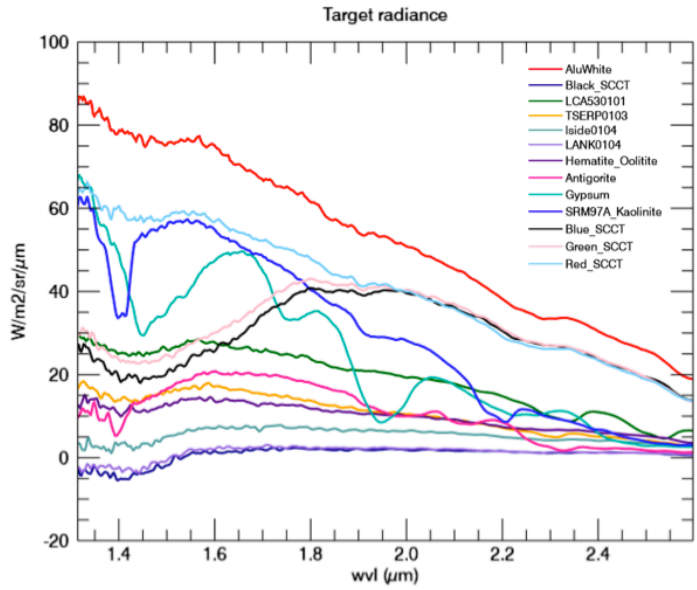

Figure 5: IR spectra of lab targets measured with the EQM

1.4 The context imaging

The Remote Micro-Imager [5] places the chemical and mineralogical analyses in their geomorphological context, as well as independently remotely imaging small details without needing to drive up to the samples. The RMI will help determine which samples within the vicinity of the rover are of sufficient interest to use the contact and in-situ instruments for further characterization. It will also provide primary science in and of itself, in providing analyses of samples that are inaccessible to contact and in-situ instruments, such as vertical outcrops in canyon or crater walls that might display strata of geological interest. Analysis of these strata may provide information on the climate history of Mars. Figure 6 shows a rock with a vein pictured with the RMI on the EQM.

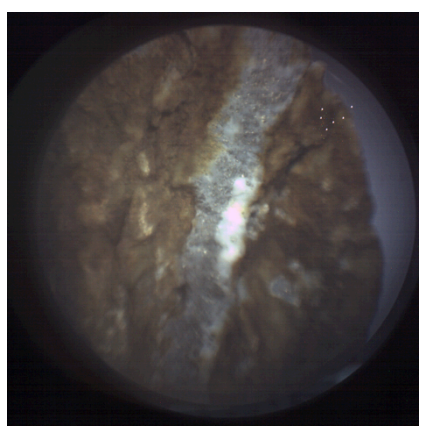

Figure 6: Rock measured with the EQM

1.5 The Microphone:

The SCM Primary science objective is to support the LIBS investigation to obtain unique properties of Mars rocks and soils through their coupling with the LIBS laser.

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In addition, other opportunistic science objectives are to monitor various artificial sounds (rover sounds), and to contribute to basic atmospheric science: wind, convective vortices, dust devils at close distance, or saltation (wind-blown sand).

1.6 On-board Calibration:

In addition, a set of calibration targets mounted nominally 1.56 m from the Mast Unit will enable periodic calibration of the instrument. Experience on ChemCam showed that these calibration targets are invaluable for LIBS, and SuperCam will fly more targets. The SCCT includes targets for Raman, VISIR spectroscopy, and RMI, as well.

2. THE INFRARED SPECTROMETER

The infrared spectrometer (IRS) [7], (Figure **7**) located on the bottom of the Mast Unit is based on the dispersion of an acousto-optic tunable filter (AOTF). The Mast Unit telescope projects the target image on the entrance hole of the IRS. A ZnSe-lens collimates the beam on the AOTF that selects the wavelength.

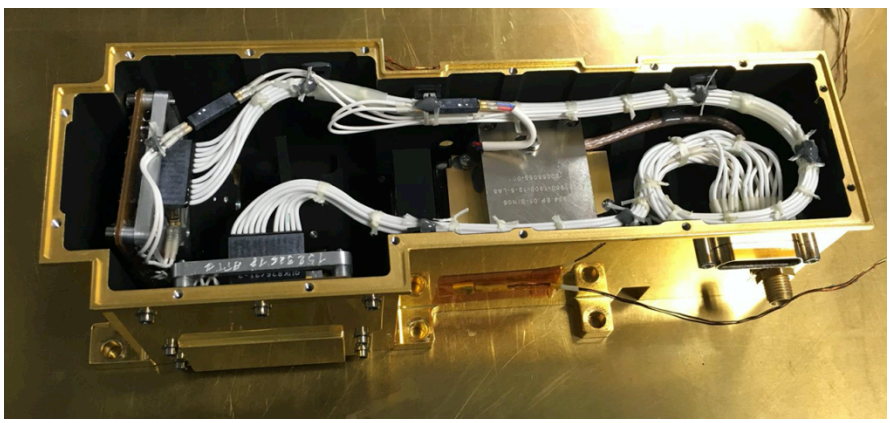

Figure 7: The Infrared spectrometer fight model. Total length = 173 mm.

The AOTF is the heart of the IRS. Its principle relies on interferences between acoustic and electromagnetic waves, creating non-periodic diffraction patterns. The phase matching principle does not generate order overlapping like in a classical diffraction grating. An electronic board generates radio frequency signal on a transducer mounted directly on the AOTF crystal generates the acoustic waves. For specific crystal and transducer geometry, there is a unique so-called tuning relation between the RF signal frequency and the output wavelength. When a RF signal at a given frequency is generated, the AOTF diffracts a zero order, one e-ray order and one o-ray order. The e-ray and the o-ray orders are diffracted at the same wavelength defined by the tuning relation. The zero-order contains all of the entrance energy except for the energy diffracted in the e-ray and the o-ray orders. The zero-order is absorbed in a light trap.

The e-ray and o-ray orders are projected on two different photodiodes using two lenses. The photodiodes are provided by Judson Teledyne Company and are made with a MCT chip mounted on a three-stage TEC that allows to cool down the chip with a gap of 80°C with respect to the spectrometer temperature.

Overview of the principal characteristics of the IRS:

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Table 1: IRS parameters

Parameter	Value	Comment
Wavelength range	[1.3-2.6] µm	
Resolution (AOTF FWHM)	30 cm-1	11.4 nm @ 1.95 µm
Resolving power	170	@ 1.95 µm (~5000 cm-1)
Sampling	15 cm-1	
FOV	1.15 mrad	
Number of spectral elements	256 max	Adjustable from 1 to 256
Acquisition mode	Wavelength scan	Adjustable among 256
Performance temperature range	[-35°C / -5°C]	Requirement met in this range

3. QUALIFICATION AND PERFORMANCE

The qualification of the instrument has been done through two models: the EQM (Engineering Qualification Model) and the FM (Flight Model). Different sensitive parts of the instrument such as the AOTF and the photodiodes have also passed intensive tests to demonstrate their ability to survive Mars environment.

At the IRS level and Mast Unit level the EQM has successfully passed shock, vibration and thermal cycles at qualification level. So far the flight model at the IRS level has passed vibration and thermal cycles at the acceptance level.

During the instrument development, on the EQM and recently directly on the flight model, performance has been measured in a representative Mars environment for the following parameters:

- Wavelength band pass and registration
- Field of view and alignment on the Mast Unit optical axis
- Resolution
- Signal to noise ratio
- Linearity in flux and integration time
- Straylight
- Relative and absolute spectral response
- Instrument transfer function

3.1 Spectral resolution

The spectral resolution has been measured using a monochromator monitored during the measurement with a lab spectrometer. For sampled wavelengths and at different temperatures of the spectrometer the IRS response is measured. A Gaussian fit of the measurement is applied to calculate the FWHM response. A deconvolution of the monochromator response is calculated to extract the IRS spectral resolution.

Figure **8** shows the IRS response to the monochromator stimuli and the extracted spectral resolution of the instrument at different temperatures. The spectral resolution meets the requirement at all wavelengths and performance temperature range.

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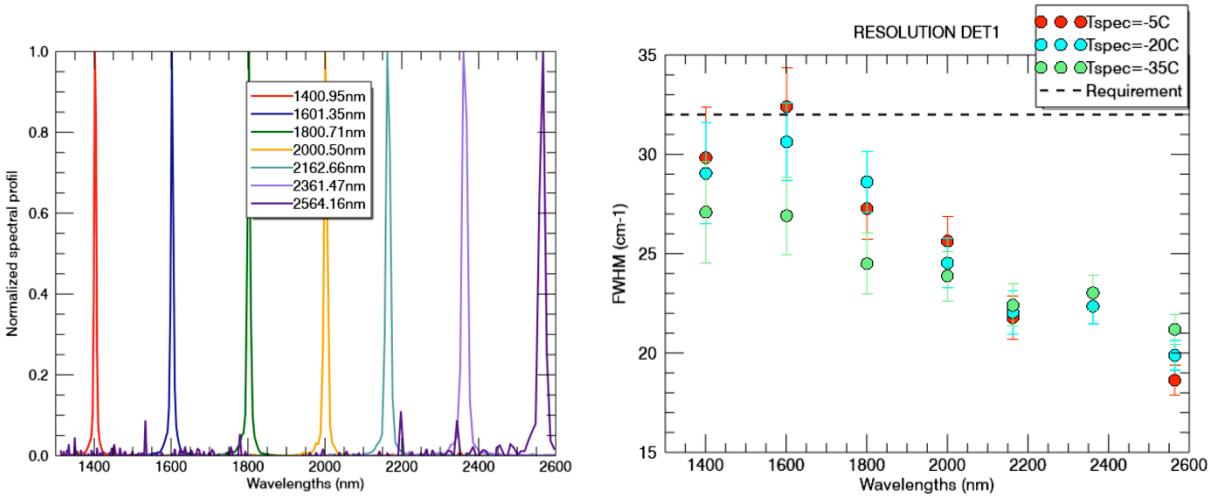

Figure 8: IRS response to different spectral stimuli by a monochromator (left) and calculated spectral resolution at different spectrometer temperatures (right)

3.2 Spectral registration

The scientific requirement shows that the spectral registration needs to be known better than ±1nm in the performance temperature range. In order to measure the registration, a Fabry-Perot interferometer associated with a calibrated lab spectrometer is used. The Fabry-Perot spectrum measured with the lab spectrometer is convolved by the IRS resolution. The positions of spectral lines of the Fabry-Perot are calculated for the lab spectrometer measurement. Simultaneously, the positions of the spectral lines measured with the IRS are calculated. The registration map is then extracted by comparison of both measurements.

Figure **9** shows the superposition of the Fabry-Perot spectrum measured with the lab spectrometer and its spectrum measured with the IRS using the calculated registration map. Relative registration with the spectrometer temperature is also shown. The registration knowledge meets requirement in the completed performance spectrometer temperature range.

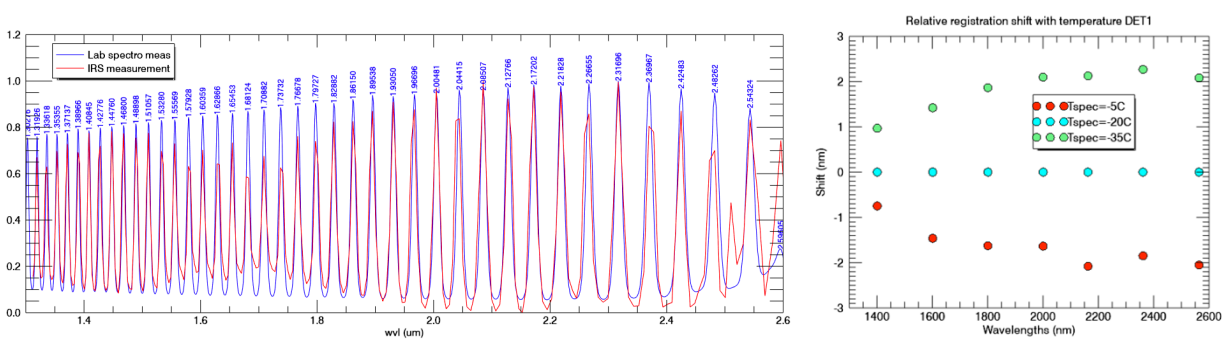

Figure 9: Fabry-Perot measurement with lab spectrometer and IRS (left) and relative spectral registration with spectrometer temperature (right).

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3.3 Signal to noise ratio

The signal to noise ratio requirement is at least 60 assuming 80 s to acquire a spectrum and background of 86 spectral elements, an irradiance of 300W/m^2 and a 30% Lambertian target albedo. This requirement needs to be met in the performance temperature range of the spectrometer.

In order to verify this requirement, noise measurements have been done with variation of the different instrument parameters such as the integration time and at different spectrometer temperatures. Depending on the parameters, a noise limit has been calculated to meet the requirement and the measured noise is compared to this limit.

Figure **10** shows the comparison with the requirement of the measured noise in all the parameters conditions. The IRS meets the SNR requirement for all parameters values and spectrometer temperatures.

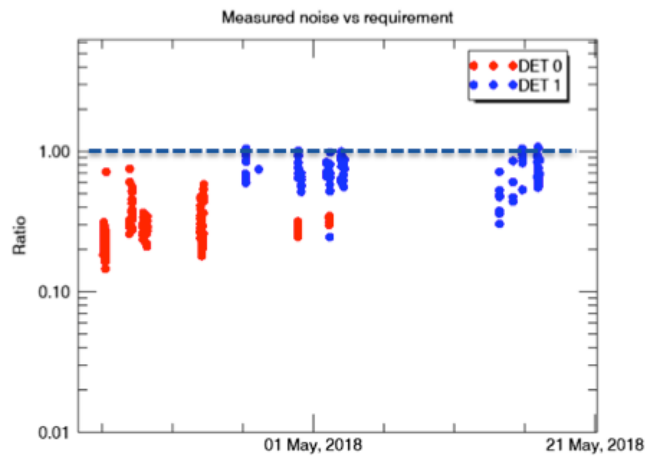

Figure 10: Noise for both photodiodes for all parameter conditions compared with the requirement

3.4 Real target measurements

On the engineering qualification model at LANL spectra of real rocks have been measured. The target is illuminated with a high infrared radiance lamp. The reflected flux is measured with the IRS integrated to the Mast Unit. The complete instrument is cooled down to -10°C. The reflectance of the target is derived using a reference measurement (spectrally flat target).

Figure **11** compares the reflectance of gypsum measured with a 5nm resolution lab spectrometer, the same measurement convolved with the IRS resolution and the IRS measurement. This high correlation of those measurements shows that the IRS is correctly calibrated in terms of spectral registration and spectral resolution.

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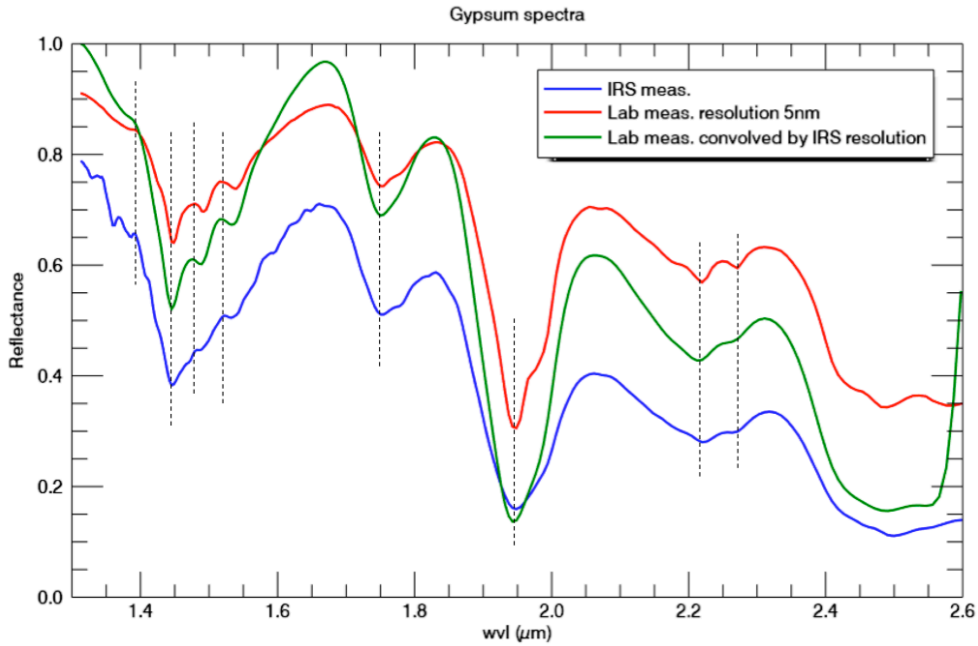

Figure 11: Comparison of gypsum reflectance measured with the IRS and with a lab spectrometer.

4. CONCLUSION

The infrared spectrometer of SuperCam for the MARS2020 mission is qualified. The flight model has been built and delivered for integration on the Mast Unit. On the flight model the performance has been verified in a thermal environment (some results are shown in this paper). Before the end of 2018, end-to-end calibration of the instrument will be done before delivery to LANL. Three months of tests and verifications will be done at LANL, coupling the Mast-Unit and the Body-Unit. In early 2019, SuperCam will be delivered to JPL, integrated to the rover for final tests before launch that is scheduled for July 2020. Among all other instruments, the infrared spectrometer will contribute to new discoveries of the mineralogy of Mars.

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