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THE SUPERCAM INFRARED INSTRUMENT ON THE NASA MARS2020 MISSION – Optical design and performance

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I. THE SUPERCAM INSTRUMENT AND IR CAPABILITY

On July 2020, NASA will launch the Mars2020 mission. This mission 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 [1]

The rover, which is in many ways similar to Curiosity rover, will embark several instruments to perform field analyses in biology, climatology, mineralogy, geology and geochemistry. As part of this payload, the SuperCam instrument, an improved version of the ChemCam instrument on Curiosity [2] is implemented for a 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 Light Induced Breakdown Spectroscopy (LIBS), a new RAMAN spectroscopy analysis and an infrared spectrometer (IRS) have been added. A context color imager is also implemented to place the analyzed samples in their geological context. A microphone will also record sounds on Mars from LIBS impacts and from the atmosphere [Pérez et al., this issue].

IR spectroscopy has demonstrated its powerful capability in the detection and identification of mineral phases through characteristic absorption features related to electronic processes, vibrational stretching and/or bending of characteristic molecular bounds [3]. The IR wavelength range on SuperCam (1.3 – 2.6 μm) provides easy identification of most minerals to be found in the Mars geological record. In addition, IR spectroscopy might provide a tool to identify complex organic compounds from absorptions at 1.7 and 2.3 – 2.5 μm due to various combinations of CH_2 and CH_3 asymmetric and symmetric stretch.

SuperCam also records atmospheric 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. Fitting the observed sky radiance to multiple-scattering discrete-ordinates radiative transfer models with gas absorption handled by the correlated-k method will make these measurements.

SuperCam consists in three units. The “Body Unit” built by the Los Alamos National Laboratory, NM, the “Mast Unit” built by a French consortium funded by CNES of 6 laboratories (IRAP as leader, LESIA, LATMOS, IAS, OMP, and LAB), and a “Calibration Target Unit” provided by the University of Valladolid in Spain. As part of the Mast-Unit, the IR spectrometer is described below.

III. THE INFRARED SPECTROMETER, OPTICAL DESIGN AND PERFORMANCES

Infrared spectroscopy is a new capability added to SuperCam [4]. Its concept is inherited from SPICAM and SPICAV instruments flying on MarsExpress and VenusExpress respectively and operates by scanning of an AOTF (Acousto-Optic Tunable Filter) [5][6]

The IRS acquires spectra of the reflected Sun on the Mars surface in the bandpass 1.3 - 2.6 μm with a 30 cm^{-1} resolution. Its mass is 430 g and it is located in the collection path of the MU telescope (Figure 1) [7]. At the

output of the Schmidt-Cassegrain telescope a set of dichroics split the collected bandpass. The light is guided to the IRS with a periscope and a set of lenses that inject the image in a 400 μm diameter pinhole with a 0.18NA and relay the entrance pupil in the spectrometer near the entrance of the AOTF.

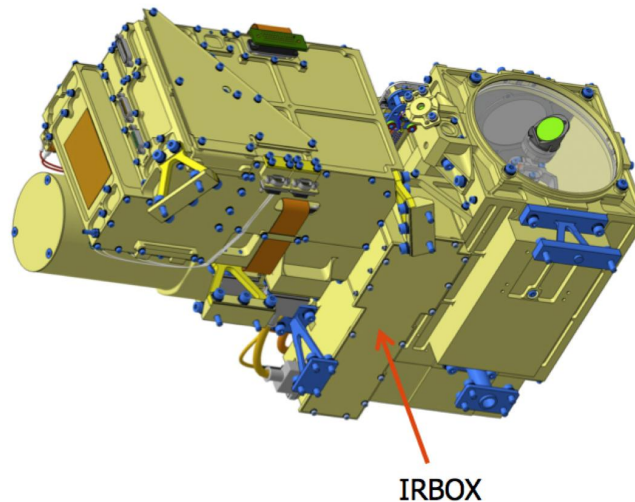


Figure 1: Infrared optical box located underneath the MU optical box

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. Applying a RF 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 whole 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 optical path inside the IRS (Figure 2) consists of:

- An entrance hole lighted by the MU-telescope
- A folding mirror and a ZnSe collimator lens
- The AOTF
- A ZnSe objective that images the 3-AOTF outputs. While the zero-order is trapped in the objective image plane, the e-ray and o-ray orders pass through
- Two photodiodes including one ZnSe relay lens that images the entrance hole on the sensitive part of the photodiode. The e-ray path is folded in front of the photodiode.

The detection is done by MCT photodiodes by Judson mounted with a front-end electronic package. In order to limit the dark current, the photodiodes are cooled using a 3-stage TEC. The e-ray photodiode and its front-end electronic are used only for redundancy, in case of failure of the o-ray photodiode.

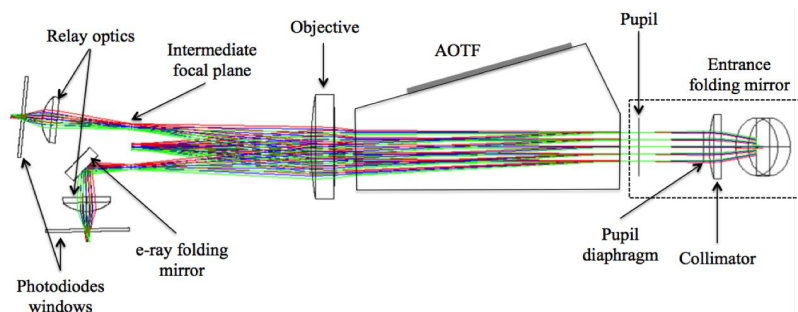


Figure 2: IRS optical layout

The principal characteristics of the IRS are described in Table 1:

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 ($\sim 5000 \text{ cm}^{-1}$)
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

Table 1: IRS main characteristics

A. AOTF DESIGN

A design for an AOTF to simultaneously diffract both “+” and “-” orders at a common wavelength has been investigated by the provider Gooch and Housego. In particular care was taken to meet the simultaneous requirements:

- Wavelength tuning range $1300 \text{ nm} < \lambda < 2600 \text{ nm}$
- Drive frequency range $30 \text{ MHz} < f < 80 \text{ MHz}$
- Maximum RF drive power 3.5 W
- Bandpass resolution $\delta\lambda \sim 11.5 \text{ nm}$ @ $\lambda = 1950 \text{ nm}$
- Deflection angle over the tuning range to be $\pm 3 \text{ mrad}$ (with a goal of $\pm 2.5 \text{ mrad}$) for both o-ray and e-ray

Such a design is possible if an input angle of 28° relative to the crystal axis is chosen as the starting-point. In addition, other parameters such as the performance across the required temperature range and meeting the size constraints are satisfied with this design.

The characterisation of the AOTF as a sub-system is the key for the knowledge of the IRS performance. This is the reason why all the delivered AOTF will be tested as part of a screening and performance evaluation before integration in the instrument. The main measured parameters are:

- The spectral bandpass
- The spectral resolution
- The tuning relation of the o-ray and e-ray beams (relation between the radiofrequency and the output wavelength)
- The pointing stability of the o-ray and e-ray beams (deflection angle over the tuning range)

B. STRAYLIGHT

The 0th order being about 500 times brighter than the scientific beams, it needs to be trapped to minimize the potential straylight. A light trap (Figure 3) is accommodated in the intermediate focal plane, where the 3 beams are well separated.

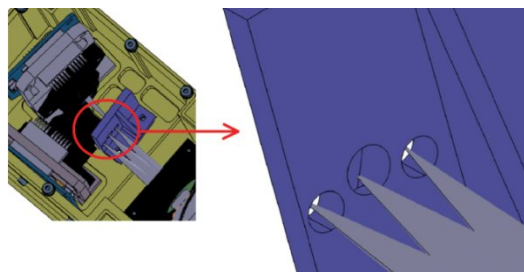


Figure 3: Light trap accommodation

The light trap is tilted with an angle of 45° with respect to the incident beam so that 2 reflections are needed before light comes out (10 left). The internal and external surfaces are coated with the PNC paint from MAP coatings. The TIS (Total Integrated Scatter) is lower than 3.5% in the $[1.3 \mu\text{m}- 2.6 \mu\text{m}]$ spectral band. As a consequence, less than 0.12% of the flux can exit the light trap.

The light trap is accommodated on a mechanical part, which has a function of a baffle in the instrument (Figure 3). Two holes let the diffracted orders reaching the focal planes. The size of this baffle is designed so that the photodiodes only see black-coated surfaces. The AOTF, which is not black-coated, is not directly seen by the photodiodes, except in the scientific geometric etendue.

As a consequence, the parasitic rays from the 0th order that can reach the photodiodes have been reflected 2 times in the light trap, plus at least 1 time on the AOTF crystal (1% reflectance) or a black-coated surface (reflectance lower than 3.5%).

As the IRS operational mode consists of acquiring the spectels (i.e. spectral elements) with dark measurements interleaved, the stray light is de facto corrected.

In addition to the light trap good practices to limit stray light are implemented as far as possible:

- A diaphragm within the entrance optics assembly limits the aperture of the optical beam before entering the AOTF.
- All possible surfaces are black coated.
- The relay lenses in front of the photodiodes are directly mounted on the photodiode assemblies to reduce the aperture of the photodiodes.

C. PERFORMANCE

SNR has been modelled taking into account observation modes, all the source of noise and the typical environment conditions on Mars in terms of solar irradiance on the target and spectrometer temperatures.

Collected scientific signal

The source input is the reflected solar flux on a purely lambertian target. The solar contribution is given by the solar blackbody radiance at 1.38AU and taking into account the Mars atmospheric transmission. A conservative coefficient parameter of 0.5 is taken into account on the reflected solar flux. The reflected solar flux is collected in a geometrical etendue $S\Omega_s$ for a given wavelength in a bandpass $\delta\lambda$.

Noise consideration

Different sources contribute to the noise:

- Thermal emission of the spectrometer (blackbody emission at the spectrometer emission). This contribution, seen in an etendue of $S\Omega_t$ is subtracted by a “dark” measurement but the photon noise on the subtraction is considered.
- The dark current signal generated by the photodiode. This contribution is subtracted by a “dark” measurement but the photon noise on the subtraction is considered.
- Some straylight is considered coming from order zero and estimated at 1% of the total source flux in the detector bandpass. This contribution is subtracted by a “dark” measurement but the photon noise on the subtraction is still considered.
- Thermal emission of warmer parts along the optical path within the scientific etendue $S\Omega_s$ at the spectrometer temperature. This contribution is subtracted by a “dark” measurement but the photon noise on the subtraction is still considered.
- Electronics readout noise
- Photon noise

Computation shows the compliancy with the requirement to get a SNR higher than 60 with the spectrometer colder than -5 °C in a maximum 80 s integration time for the acquisition of 86 spectels. Figure 4 shows two examples of the SNR in typical observation configuration on Mars with a spectrometer at -5°C and -20°C.

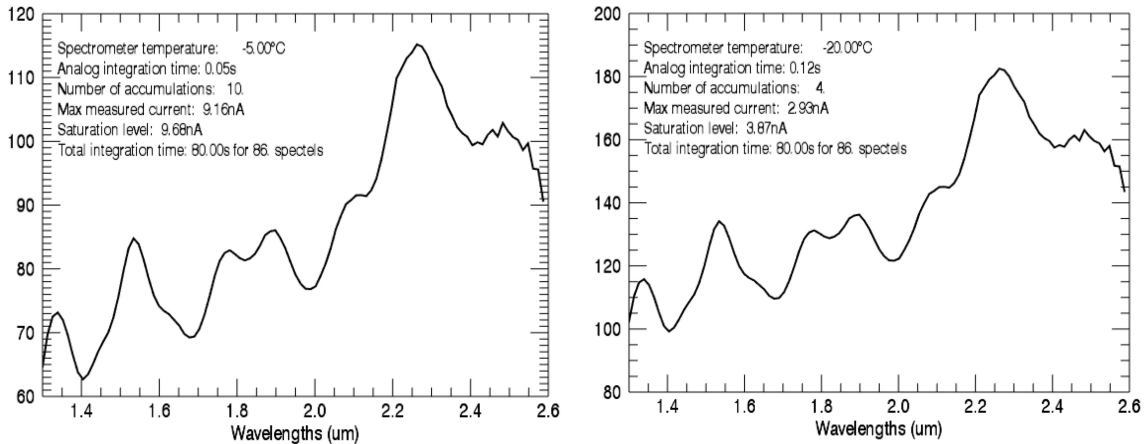


Figure 4: SNR vs wavelengths (spectrometer temperatures: -5°C (left) / -20°C (right))

As an example of the IRS performances, measurement has been done using the first built model. A CH₄ gas cell transmission has been measured and compared to its transmission measured with a lab spectrometer at higher spectral resolution and convolved by a Gaussian profile at 30cm⁻¹. Figure 5 shows the compliancy of the instrument in terms of spectral resolution. Also, this measurement has been used for spectral registration of the instrument.

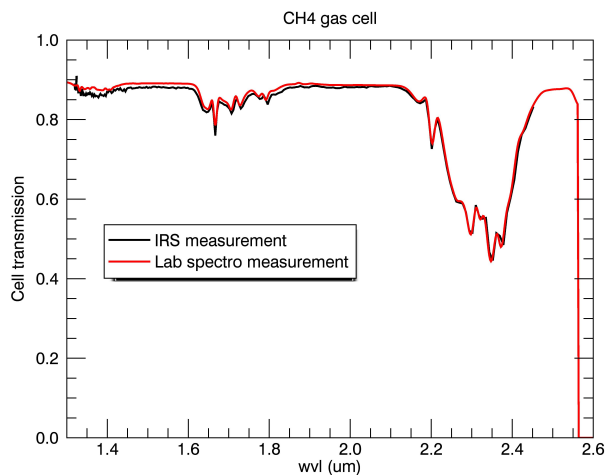


Figure 5: IRS spectrum of CH₄ gas cell

IV. CONCLUSION:

The infrared spectrometer of SuperCam on Mars 2020 (launch July 2020) is a new capability with respect to the ChemCam instrument on Curiosity (in operation). The challenge for optical designers is to implement this spectrometer with reduced mass and volume, in an already mature instrument suite. An AOTF-based spectrometer design has been chosen for its compactness and heritage from previous space instruments. The first tests performed on an engineering model show that the instrument is compliant with requirements. We have already started to build the Engineering Qualification Model in order to check its robustness under relevant environments. The Flight Model manufacturing and tests will start early 2017.

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