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How to improve a critical performance for an ExoMars 2020 Scientific Instrument (RLS). Raman Laser Spectrometer Signal to Noise Ratio (SNR) Optimization

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Abstract

The Raman Laser Spectrometer (RLS) is one of the Pasteur Payload instruments, within the ESA's Aurora Exploration Programme, ExoMars mission.

Raman spectroscopy is based on the analysis of spectral fingerprints due to the inelastic scattering of light when interacting with matter.

RLS is composed by Units: SPU (Spectrometer Unit), iOH (Internal Optical Head), and ICEU (Instrument Control and Excitation Unit) and the harnesses (EH and OH). The iOH focuses the excitation laser on the samples and collects the Raman emission from the sample via SPU (CCD) and the video data (analog) is received, digitalizing it and transmiting it to the processor module (ICEU).

To extract useful analytical information from Raman spectroscopy the spectral quality has to be increased. This quality is mainly limited by the signal to noise ratio (SNR). The SNR can be improved both increasing the intensity and decreasing the noise.

The RLS EQM Instrument has been characterized and configured for improving its high levels scientific performances, the SNR.

1. Introduction

One of the instruments of the ExoMars mission Pasteur Payload, within the ESA's Aurora Exploration Programme, is the Raman Laser Spectrometer (RLS). RLS will perform Raman spectroscopy for the first time in an out planetary mission. To do it, RLS have required different main elements:

- SPU, Spectrometer Unit, in charge of the spectral analysis. The CCD detects the data and transfers the spectrum to the ICEU.
- iOH, Internal Optical Head, responsible of focusing the excitation laser light in the sample (maximizing SNR).
- ICEU, Instrument Control and Excitation Unit, provides the excitation signal and the operational control of the instrument.

During the EQM integration and testing campaign, the instrument has been submitted to an continuous optimization process, operation, functionality; operation SW; and also obtaining representative data with real samples (SNR, accuracy…) which depending on a set of configurable parameters allows performances improvements:

- Excitation laser (power stability and wavelength)
- Autofocus to get the spectra in the optimum position.
- CCD control: gain, offset

- Operation: number of acquisitions (N) and integration time

- Thermal control (CCD and laser)

and also using analytical tools like the radiometric model.

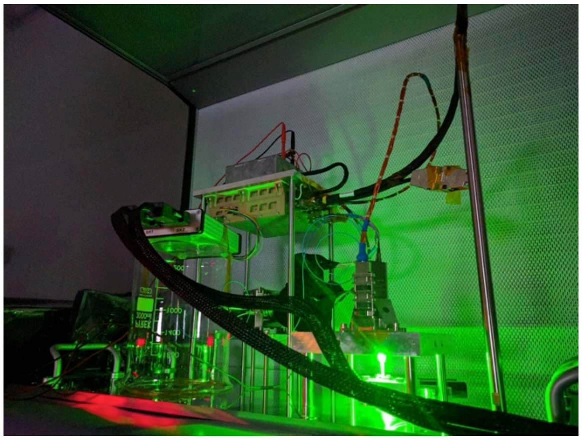

Figure 1: RLS EQM instrument test set-up

2. RLS instrument SNR dependability

The main sources of noise arise from the sample, the background, and the instrument (Laser, CCD, focuss, acquisition parameters, operation control). In this last case the sources are mainly perturbations from the optics, dark signal and readout noise. Also flicker noise arising from laser emission fluctuations can be considered as instrument noise.

In order to evaluate the SNR of a Raman instrument in a practical manner it is useful to perform end-to-end measurements on given standards samples. These measurements have to be compared with radiometric simulations using Raman efficiency values from literature and taking into account the different instrumental contributions to the SNR.

2.1 RLS Laser (ICEU)

The Raman Laser Module generates the optical monochromatic. The laser light is green (532.0 +/- 0.5 nm) and the output power is set by design to 36 mW.

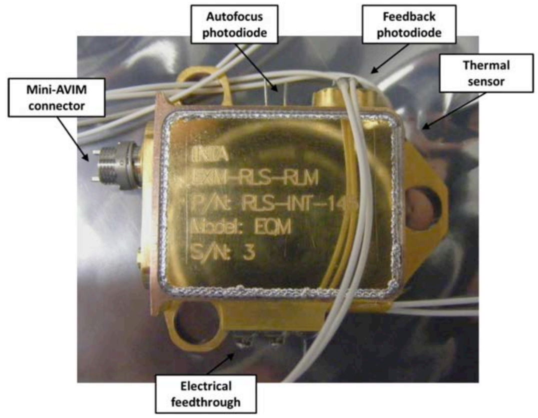

Figure 1: RLS laser EQM

The Raman Laser Module comprises a number of components whose functionality is guaranteed by the ICEU. Some of then are linked to the SNR performance:

- Photodiode feeds the ICEU laser driver with an electronic signal proportional to the laser beam output power.

- Autofocus photodiode receives the reflected beam from the sample. RLS On-board SW commands the AF system to guarantee that the iOH is optimally focused and SNR is maximized.

- Thermal control (TEM) to get the laser temperature in set point from any non operative conditions; once this temperature is reached on the laser can be switched on and thermally controlled for being able to provide the desired optimum laser performances in terms of power stability, peak width, peak stability and non secondary peaks.

2.2 RLS CCD (SPU)

The RLS CCD is a NIMO (non-inverted) controlled by the FEE (Front end electronics):

- Provides the required biasing and control signals to drive the CCD (within the SPU function). The commanding of the FEE function comes from the FPGA (processor module inside the ICEU) and the biasing is mainly fed from the internal supply lines generated at the power module

- Receives the video data coming from the CCD (analog), digitalizing it and transmitting it to the processor module

When acquiring Raman spectra, there are many instrument parameters, especially for the CCD device, that must be configured to optimize spectra (temperature, gain, offset) and SNR performance. Adjusting the CCD the sensitivity of the CCD (Gain), we can help boost the input throttle back video noise as appropriate. On the other hand with the video offset we can scale the real signal generated by the illuminating light.

The CCD is thermally controlled by a TEC that is capable of getting the CCD temperature cooled down from any hot operative conditions until a commanded temperature; to provide the desired optimum CCD performances in terms of noise reduction. As lower is the temperature the dark signal drops with a higher factor.

2.3 RLS spectra acquisition

Two operational-level parameters, Integration Time (ti) and Number of Accumulations (na), are the key parameters of Raman acquisition. Both helps the optimization of the signal/noise ratio (SNR).

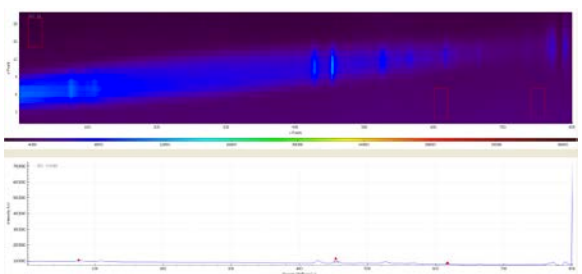

Figure 3: RLS EQM spectra acquisition over the CT

Performing accumulations in stable conditions. The laser excitation source needs to be stable and in similar thermal conditions than in previous acquisition.

Autonomous algorithm will be implemented in the RLS FM on board SW for helping the SNR improvements:

- Fluorescence removal
- Acquisition parameters estimation

3. SNR measurements

Signal to Noise ratio (SNR) values achieved by the instrument are considered end-to-end and needs to be estimated experimentally.

With the correct instrument configuration and the HW in operative conditions; the SNR for different samples material (Silicon, Cyclohexane, Calcite and Hematite) is achievable.

The acquisition time defined (one second) has been understood as total integration time (multiple acquisitions are allowed).

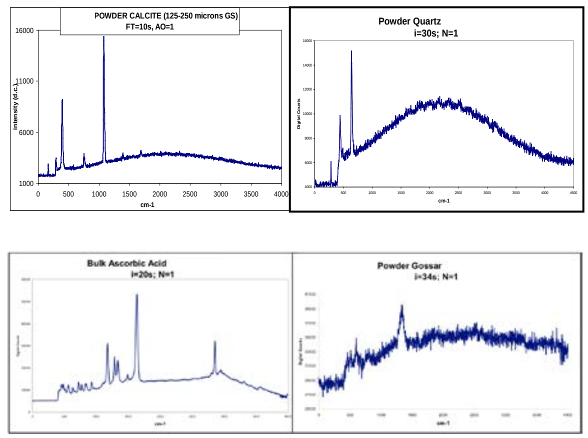

Figure 4: RLS EQM SNR analyisis over different materials

4. Summary and Conclusions

The RLS EQM instrument performances results and its functionalities have been demonstrated in accordance with the science expectations. The Instrument obtained SNR performances in the RLS EQM will be compared experimentally and via analysis, with the Instrument Radiometric Model tool.

The characterization process for SNR optimization is still on going. The operational parameters and RLS algorithms (fluorescence removal and acquisition parameters estimation) will be improved in future models (EQM-2) until FM Model delivery.

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