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Keywords:	Combined science, Calibration Target, Raman spectroscopy, Infrared spectroscopy, ExoMars

RLS Calibration Target design to allow onboard combined science between RLS and MicrOmega instruments on the ExoMars rover

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Abstract

The ExoMars rover will be launched in 2020 with several instruments that will be able to perform combined science between instruments, for the first time allowing the instruments to analyze the same spots of the same samples. The Raman Laser Spectrometer (RLS) instrument Calibration Target (CT) includes a polyethylene therephtalate (PET) calibrant that has been subject to a series of tests to qualify it for space and to properly characterize its behavior during mission, in order to be used by RLS for the verification of the instrument calibration and health status. In addition, the RLS CT includes some patterns that the instruments will detect and that will be used to establish their relative positions, thus becoming a key element in order to facilitate the spatial correlation of the instruments, and thus the combined science. The results from the joint tests performed by the RLS and MicrOmega instruments support the operational approach designed for the ExoMars rover, which allows complementing the necessary collaborative science onboard ExoMars with the autonomous RLS operation.

Keywords: Combined science, Calibration Target, Raman spectroscopy, Infrared spectroscopy, Exomars

Introduction

The ExoMars mission of the European Space Agency (ESA) will send a rover to Mars in 2020 with the main objective of providing insight to the present or past existence of life in the red planet [1]. Compared to other Mars missions such as the Mars Exploration Rovers Spirit and Opportunity, the NASA Mars Science Laboratory (MSL) rover Curiosity, or even the Mars 2020 rover mission to be sent to Mars by NASA at the same time as ExoMars, the European rover will feature two unique capabilities unprecedented on the exploration of Mars. On one side, the capability of analyzing samples from the subsurface down to depths of two meters, where the potential organic material is not affected by the ionizing radiation received at the surface. On the other hand, the ExoMars rover includes a laboratory with a sample carrousel that will allow the analysis of the same sample, in the same spots, by different instruments. These two features constitute an important step forward for in situ analyses on Mars, as they provide the real possibility of analyzing potential organic material present on the planet's surface, while allowing the instruments to verify and complement each other results by analyzing the exact same areas of the sample, at micrometric scale.

These features are possible in the ExoMars rover[1] thanks to the nested-investigations concept design, which allows it to analyze from panoramic to molecular scale with its Pasteur Payload, as it incorporates instruments and systems capable of performing nested experiments, from the panoramic cameras to spectroscopic and molecular analysis, including also the necessary sample extraction and preparation. Concretely, the rover includes a subsurface drill capable of extracting samples from the shallow subsurface of Mars, down to a depth of two meters. The collected materials are then crushed and served to the instruments of the Analytical Laboratory Drawer (ALD) in a carrousel with the Sample Preparation and Distribution System (SPDS). This system includes a Refillable Container (RC) in which the crushed sample will be placed and flattened. The instruments in the ALD will then be able to analyze a flat surface of the powdered sample when the RC is placed by the carrousel below them. This allows analyzing the same sample surface with several complementary techniques, such as Raman spectroscopy (RLS)[2], visual plus infrared spectroscopy (MicrOmega-MICR)[3-5] and laser desorption mass spectrometry LDMS (MOMA)[6], instruments forming part of the ALD.

The capability of the ExoMars rover to analyze the same sample with the different instruments of the ALD provides the possibility of performing combined or cooperative science between the analytical systems. The sample characterization will be performed sequentially by the three instruments of the ALD, starting with MicrOmega, followed by RLS, and then MOMA LDMS. This means that it is possible to take the previous instrument analytical results in consideration to improve the analysis of the next, to do some kind of "directed" sample characterization (e.g. analyzing a spot that is considered interesting by a previous instrument) in addition to the automated analysis performed by each instrument. Concretely, this analytical concept has been implemented onboard the rover software, to allow the automated cooperative science between RLS and MicrOmega, even without the intervention of operators, while also respecting the automated operation of each instrument. The cooperative analysis with MOMA LDMS will require a previous study by the scientists on ground.

MicrOmega provides a measurement field of view (FoV) of ~5x5 mm^2 [3]. RLS performs micro Raman studies along a line traced by the carrousel with a 50 microns spot[2] and MOMA LDMS presents a spot size of ~400 microns[6], with a central effective size of around 150 microns. Given the differences among the instruments FoVs, it is of paramount importance to ensure the mechanical alignment between the different instruments, especially between RLS and MicrOmega, given the possibility of performing automated combined science. In this sense, the RLS instrument features a Calibration Target (CT) that has been implemented with features that are detectable both by the RLS and MicrOmega instruments to both facilitate the calibration verification of the RLS instrument, as well as the spatial cross-registration between both instruments.

The Raman Laser Spectrometer (RLS) [2] is a Raman spectrometer with a continuous wave excitation laser with a wavelength of 532 nm and a power between 10 and 20 mW, with a spot size on the sample of 50 microns. The spectrometer has a spectral range between 533 and 676 nm, with a spectral resolution between 6 and 8 cm^{-1}. The optical head of the instrument provides autofocus capabilities, establishing the focus position based on the intensity of the signal reflected on the sample. To do so, the laser includes a photodiode which measures the reflected light on the sample, providing higher intensity when the sample is better focused. Based on this intensity, the autofocus algorithm implemented will move the optical head lens to modify the focus position, searching for the maximum intensity.

The RLS instrument includes two Calibration Targets in the ultra-clean zone (UCZ) of the rover, these being placed on the carrousel that positions the Martian samples. These CTs have a double function: 1- to ensure and verify the calibration status of the instrument and 2- to ensure the spatial cross-registration of the MicrOmega and RLS instruments inside the ALD. The reason behind the presence of two CTs for RLS is an operational constraint, which makes it impossible to have a CT under the RLS instrument during cruise without affecting the sample surface during operation on Mars after the analysis with MicrOmega. By using 2 CTs it is possible to guarantee the presence of a CT under RLS during cruise, while allowing the RLS calibration to happen before the Raman acquisition of the Martian sample already analyzed by MicrOmega.

The two RLS CTs are not identical. Even if their base material and design is the same, one of them is equipped with some laser and mechanically-performed patterns that are visible both by MicrOmega and RLS, allowing the cross-registration of the sample area that RLS will analyze with respect to the MicrOmega FoV.

In this paper, the objective is double. On one hand, the RLS CT design is described to show how it fulfills both the requirements of allowing a proper verification of the RLS calibration while surviving the harsh conditions of space and space qualification and its expected performance, as well as providing a means for the spatial cross-registration of RLS and MicrOmega FoVs. On the other hand, the paper addresses how the combined science improves the scientific return of the mission by describing some joint tests and experiments already performed in the framework of the ExoMars mission with other instruments of the ALD, specifically, between RLS and MicrOmega.

The Calibration Targets of the RLS instrument

RLS CT design for the verification of the RLS health status

The two RLS CTs included in the ExoMars rover (Figure 1b) are placed on the same carrousel that will host Martian sub-surface samples, allowing the calibration of the instruments by turning the carrousel and placing the corresponding CT under the instrument probe. Given that the CTs are placed in the UCZ of the rover, and the proximity to very low-threshold detection instruments such as MOMA GCMS, the cleanliness and contamination requirements are extremely tight, and unprecedented in any other previous mission to another planetary body. This limits the quantity of organic materials to be used for the CT, but also implies very hard cleaning and sterilization methods, including bakeouts at very high temperatures (>110ºC). The requirements imposed to the RLS CTs included, in addition, a very low outgassing rate, to have multiple peaks evenly distributed along the spectral range of the instrument, small mass (less than 20 mg), compatibility with sterilization temperatures (>110ºC) and organic solvents, stable behavior in large temperature ranges (-50ºC to 40ºC), resilience to ultra-violet radiation, etc.

The main requirement for the selection of the material was to survive a wide range of temperatures while providing multiple peaks evenly distributed along the spectral range, as shown in Figure 1a. Many mineral and organic materials were tested and, according to the obtained results, Polyethylene Therephtlate (PET)[7] was chosen as optimal candidate. This same material has also been selected as part of the payload on the NASA Mars 2020 SuperCam Calibration Target.

As previously stated, the requirements for organic material inside the UCZ of the rover were extremely tight, with both CTs using a total mass of PET <20 mg. In order to fix this small quantity of calibration material to the rover carrousel, a configuration as shown in Figure 1c is used. The calibrating material consists of a PET hat-like disk with a visible surface of 2.4 mm diameter. The main body of the mechanical assembly is aluminum coated with Iridite 14-2, a chromate conversion coating to guarantee a good behavior against corrosion. The PET is then mechanically fixed to the main body by means of a stainless-steel cap which is screwed on top of the main body.

In order to verify the compliance with the requirements imposed to the CT, as well as to have a proper characterization of the calibration material together with some insight on the potential evolution of the CT spectral response in the expected environment on Mars, several tests were performed.

PET was tested at different temperatures in the operational range of the mission, to verify the spectral response of the polymer in the actual operation conditions. This analysis was performed by acquiring spectra of the PET inside a small thermal chamber at ambient, 0ºC and -20ºC temperatures, in a 40 mbar vacuum environment. The results showed that, in terms of peak positions, the potential variations of the spectrum at different temperatures are negligible when analyzed with the RLS instrument, while there is a trend of signal-to-noise ratio (SNR) decrease (between 15% and 35% depending on the analyzed spot) when temperature falls from 293 to 253ºK.

Outgassing tests (both static and dynamic) provided values in line with the mission requirements. In addition, a very long (150h) bakeout at 125ºC in vacuum was performed on the PET to ensure a proper degasification of the material included in the UCZ, as well as a final sterilization process of the complete assembly of 120h at 115ºC. The preliminary tests performed on the selected PET at those temperatures showed no modifications in the spectral profile before and after, except for a slight increase on the background signal. Considering that the baking temperature is higher than the glass transition temperature of the selected PET, the background increase can probably be related to a slightly worse ordered recrystallization of the polymer. High cooling temperature slopes, however, showed to result in higher disordered structures than slow cooling, so, by controlling the cooling slope, the resulting PET was little affected by the very high temperatures. Taking all this into consideration, the procedures for the qualification were properly adjusted. During the qualification campaign, two different ovens were used for three test units. Two were baked in the same oven as the delivered units (CT3 and CT4), and one in the second oven (CT5) due to a lack of space. Then, the PET of the three units were analyzed with Raman before and after the qualification campaign, obtaining the results depicted in Table 1. This characterization was done with constant acquisition parameters, concluding that there was no SNR loss after the baking, and that even for CT3 and CT4 the SNR was even better (explained by a slightly better crystallization due to the difference in the cooling curve of the two ovens).

The ultra-violet (UV) radiation on Mars has been thoroughly studied and investigated in-situ[8] and is dependent on many factors such as latitude, season[9], suspended powder in the atmosphere[10], etc. In any case, it is higher than on Earth, thus potentially highly affecting the organic materials present on the Martian surface. The RLS CT will be enclosed behind several metallic layers in a very dark environment that will protect the internal parts from the ionizing radiation. Nevertheless, a test was performed by means of the PASC chamber[11,12] which simulates the environmental conditions of Mars, including UV radiation. A 1cm diameter, 5mm thick PET sample extracted from the RLS CT PET batch was subjected to a continuous source of UV illumination for 130h with an irradiance on the sample of 30 W/cm^2. The total dose applied to the samples was the same as the expected equivalent dose received by the ExoMars rover during its nominal mission (140 sols), considering the calculated UV flux at the Martian equator[13], and approximating the values with the latitude of Oxia Planum, landing site of ExoMars. The results of the experiment showed a slight modification in the coloration (yellowish tone) of the PET (which is white) in the exposed areas. However, the spectral signature of the PET seemed quite unaffected in terms of peak positions and intensities. The SNR, however, was negatively affected by the radiation effects, as shown in Table 2. All peaks were nevertheless detectable. Considering the results of the test, the UV incidence on the CT was considered of minor importance, given that all the relevant spectral features are detectable and especially considering that the PET part will be safe from the UV radiation in the interior of the rover ALD. However, these results have also been useful for the selection of PET as part of the SuperCam Calibration Target onboard the Mars 2020 mission, which is external and thus exposed to the Martian environment. This sample on the SCCT is also aimed at the study of the evolution of organics in the Martian environment.

The set of tests performed as part of the RLS CT development and qualification campaign are aimed at characterizing the calibrant (PET) spectral response for the proper characterization of the instrument by comparing both the background intensity and peak spectral response on ground, vs. along the mission span. These tests offered a thorough understanding of the expected behavior of the calibration target PET once on the surface of Mars, providing the means to help understand the RLS instrument end to end performance during operation.

RLS CT design for spatial cross-registration with MicrOmega

Given the different scales of FoV between the different instruments (the MicrOmega FoV of ~5x5 mm^2 while the RLS instrument can access a 50 microns thick line), it is actually impossible to know precisely the relative positions of the corresponding FoVs based only on the mechanical alignment of the rover parts, as the mechanical uncertainty due to the manufacturing tolerances and thermal effects is in the order of magnitude of the RLS FoV. Thus, it is not possible to exactly establish the relative positions of the instruments beforehand. It is also not possible to measure it afterwards given that, once the UCZ is closed mounted, it is no longer possible to access the internal part of the UCZ to measure the relative positions of the instruments.

Thus, the only alternative is to use the instruments themselves to calculate their relative position, which can be done by analyzing the same known sample. In this case, it was decided that the RLS CT would be said known sample. For the RLS CT to be visible by MicrOmega, several characteristic features were introduced in one of the RLS CTs, so these features could be used by MicrOmega to univocally identify the RLS path (of course, the RLS instrument will need to analyze these features as well) on the MICR FoV, and thus their relative positions. This will then allow the combined science between the instruments, providing the possibility of precisely moving the rover carrousel so the RLS instrument is able to analyze a spot previously analyzed by MicrOmega.

The RLS CT design includes two different types of marks –mechanical and laser-induced, see Figure 2a and b– in order to benefit from the different inputs obtained by the RLS instrument: concretely, the RLS instrument can analyze the molecular composition of a sample in base of its Raman spectrum, but also can use the autofocus photodiode to identify the focus position, based on the intensity received from the reflected light. The laser-induced marks inflict a modification of the molecular structure of the PET that is detected with Raman spectroscopy, while the CT surface is mechanically milled in two different planes, with a mechanical step of 70 microns.

The laser marking consists of a pattern of three unparallel lines (they are rotated -15 and +20º each with respect to the central line) crossing the PET disk transversally to the carrousel moving direction, so the instrument will cross over the lines. The laser marks are induced using a Datalogic Ulyxe laser marking system. The molecular structural modification caused by the laser on the lines is easily detected by Raman spectroscopy.

The mechanical milling of the PET was performed by a numerical milling machine with a 30 microns diameter mill, creating a pattern on the surface of the PET as shown in (Figure 2a and b), with a depth of 100 microns. As a result, two sample planes at different heights with slightly different surface rugosities are observed. This is convenient as the RLS will be able to detect the height differences between one plane and the other, and MicrOmega will be able to identify the different rugosity of both surfaces.

These characteristics make that both the RLS and MicrOmega instruments can analyze the characteristic features of the RLS CT, in order to univocally know the relative positions of the instruments, favoring the combined science on the ExoMars mission.

Combined science between MicrOmega and RLS

The ExoMars rover presents, for the first time in the robotic exploration of Mars, a suite of instruments capable of analyzing the same samples, in the very same spots at a micrometric scale. This is achieved thanks to the carrousel concept implemented on the rover, which will sequentially place the Martian powdered-sample below the MicrOmega, RLS and MOMA LDMS instruments. This will provide a unique opportunity to perform combined science among the different instruments of the rover.

Given the intrinsic differences on the FoVs of the instruments, MicrOmega (FoV ~5x5 mm^2) will be able to analyze both the RLS (50 microns spot) and MOMA LDMS (~150 microns effective spot) sample paths, being the spatial cross-registration of the relative positions necessary for MOMA-MicrOmega, and RLS-MicrOmega. However, given the micrometric scale of their FoVs, there is a high chance that the RLS and MOMA LDMS paths do not overlap on the same sample spot.

The rover software operation concept foresees the possibility of performing an autonomous combined science between MicrOmega and RLS, with the RLS analyzing interesting spots detected by MicrOmega (the interest of these regions being automatically estimated onboard following the guidelines of the ExoMars scientific team). This implementation is based on the fact that the RLS and MicrOmega instruments might operate during the same sol, without any possibility of ground intervention. The MOMA LDMS analysis, on the other hand, will happen in a different sol than RLS and MicrOmega. Thus, the MOMA team will be able to use both MicrOmega and RLS inputs to define their operation strategy. For these reasons, on this paper, the focus is placed on the MicrOmega-RLS combined science.

Spatial cross-registration of MicrOmega and RLS

The characteristic features implemented in the RLS CT will be analyzed and detected during the initial phases of Mars operation by MicrOmega and RLS in order to establish the relative positions between the MicrOmega and RLS instrument, facilitating the detailed characterization of the spatial correlation necessary for the combined science.

The RLS instrument detects the CT features in two different ways. 1- The laser marks are detected based on their Raman signature, given that the matrix material (PET) molecular structure is modified by the laser and thus is detectable with the spectrometer. The spectral effect is given by a high increment on the background signal of the spectrum, as shown in Figure 3a. Even if the transition between the PET and the laser mark is not totally abrupt, by analyzing the acquired spectra it is possible to decide if the acquired spectrum corresponds to a marked or unmarked part of the CT. Figure 3b shows how the approximated width at half maximum of the curve obtained by integrating the spectra areas is representative of the thickness of the line (between 80 and 100 microns). 2- The mechanical marks, which provide two different planes on the CT surface, can be identified as well based on the spectral features, but also by means of the RLS autofocus photodiode, which measures a higher intensity of the reflected light when in focus (see Figure 3c).

Then, by measuring the distance between laser and mechanical marks, it will be possible to know the position of the path of analysis on the rover carrousel.

In order to test the RLS capabilities to detect the CT features, as well as to properly characterize the flight CT, a complete Raman mapping of the CT was performed with the RLS ExoMars Simulator[14-16], covering the complete CT surface in steps of 20 microns, acquiring a spectrum at each spot with a fixed integration time, adding a total of more than 12 thousand spectra. The representation in Figure 4 shows, at each pixel, the spectrum integrated area in the corresponding position of the CT surface. It is easily observed how the laser marks are very clearly detected, as are the borders between the upper and lower planes of the CT.

To test the autofocus photodiode capability of detection of the mechanical marks, the RLS FM was used and several lines were swept on the CT, acquiring three housekeeping values from the autofocus photodiode at each point. The result showed (see Figure 5) that the housekeeping data from this photodiode will complement the Raman analysis for the characterization of the path followed by the instrument.

The RLS CT has also been analyzed with the MicrOmega EQM, which provides a 5x5 mm^2 FoV with a spatial sampling of 40 microns. The flight version that will operate on Mars has also a 5x5 mm^2 FoV, but with a spatial sampling of 20 microns.

The analysis with MicrOmega shows that both the milled part of the CT and the laser marks can be properly identified. In particular, the analysis of the monochromatic images shows a reflectance contrast at the edges of the milled parts (Figure 6a and b). The roughness differences between both planes, and in particular the marks made by the milling, can be observed and used to retrieve the pattern drawn on the CT. The laser marks can also be distinctively seen on the monochromatic images (Figure 6a and c). In addition to the reflectance contrast, that by itself enables to identify both the edges of the milled parts and the laser marks, it can be observed that the reflectance spectra exhibit different features over the areas that were shot by the laser, highlighting a modification of the surface composition of the PET material (Figure 6d and e). The laser marks can thus also be detected by MICR using the spectral dimension of the dataset, which provides an additional and potentially more robust identification means than simple albedo difference. Using the latter technique, laser marks, as seen by the MicrOmega unit, are typically 2-4 pixels large, corresponding to 50-100 microns, in agreement with the laser marks thickness.

Based on the detection of the patterns by MicrOmega and RLS, it will be possible to assess where on the MicrOmega FoV will the path of analysis of RLS be. This exercise will be done during the calibration phase on Mars, getting their spatial cross-registration to ensure successful combined science experiments on the ExoMars rover on Mars.

Combined operation RLS-MicrOmega

Joint test with MicrOmega EQM

MicrOmega and RLS will provide complementary mineralogical information about the sample composition as well as first order characterization of organics if present. MOMA targets more specifically volatiles, in particular organics, with a very high sensitivity, and is able to give quantitative information about their chemical composition. Compounds of major interest (e.g. organics, phyllosilicates, carbonates) are expected to be minor within the samples and localized in specific spots. Sequential analysis of these specific locations by all three techniques will be required in order to achieve an in-depth characterization, in particular investigate the potential organic content associated to some specific mineral phases. It thus constitutes a key aspect to reach the scientific objectives of the mission.

These combined analyses can be performed by using MicrOmega capability to first characterize the sample composition over a large area, and then provide the location of targets of interest to RLS and MOMA through the use of automated algorithms[17] onboard the rover.

In this section we describe a test that simulates this protocol, in a joint test with the MicrOmega[3] EQM and the RLS ExoMars Simulator[14], which can simulate the carrousel motion with its two-axis positioning stage.

Two samples were selected for the combined science test. Sample 1 is a mixture of different salts (carbonates and sulfates) and phyllosilicates, with a grain size distribution ranging from a few microns to ~315 microns. Sample 2 corresponds to a mixture of olivine (forsterite and fayalite) with carbonates, with a grain size distribution ranging from a few microns to ~315 microns. In particular, a few grains of dolomite were added atop the sample once put in the sample container. The samples mass compositions are detailed in Figure 7.

The test sequence consisted on placing the sample under the MicrOmega FoV, and then running a typical science sequence (320 science channels covering the 0.99-3.6 μm range). Then the algorithms for detection of interesting spectral features were run. During this test, carbonates were specifically targeted within the samples. These compounds are linked to the evolution of the Martian atmosphere and climate and are thus key targets to understand the processes related to liquid water, being good candidates for the combined science test. After detection of the interesting spots, these spots are placed under the RLS instrument for analysis. Finally, and for comparison, a blind test is performed by the RLS instrument on the powdered sample (fully automated analysis without taking into consideration the MicrOmega results)

The combined science analysis on sample 1 showed that MicrOmega detected a few spots rich in carbonates, their corresponding coordinates being extracted from the MicrOmega data (Figure 8 and Table 3). Then, the targets were positioned for RLS on the calculated spots, obtaining the results on the corresponding center positions of the detected clusters shown in Figure 8b. In this case, MicrOmega detected the presence of carbonate signatures while RLS detailed the corresponding mineral phase (Figure 8d), highlighting the complementarity between these two spectroscopic techniques. Table 3 summarizes all the results. The automated (blind) analysis performed by the RLS instrument provided the results shown in Figure 8e. In this analysis, the RLS instrument was capable of detecting all the mineral phases found in combined mode, in several cases with better spectral quality. In addition, RLS found traces of anhydrite, supposedly not present on the sample, but probably transitioned from gypsum after some process of dehydration.

The analysis of sample 2 by MicrOmega detected some spots rich in carbonates (anhydrous and OH/H_2O rich carbonates), and the corresponding coordinates of a few targets were extracted from the MicrOmega data (Figure 9a, b and c). As the criterion for carbonate detection also works for organics, the small (1-2 pixels) and widespread spots identified by the algorithms and associated to olivine, are interpreted to be organics that were in the olivine samples.

After the MicrOmega test, the selected sample spots were placed under the RLS instrument. Differently from sample 1, in this case, instead of performing a unique spectrum on the exact spot, a 9-point analysis was performed with the RLS instrument. The calculated spot placed in the center of a 3-by-3 grid for target A, with 100-micron steps. For Targets B to D, the calculated spot was placed in the center of a 9-point line with 50-micron steps. Figure 9d shows a summary of the detected mineral phases by RLS on the spots indicated by MicrOmega. In addition, an 8-point automated (blind) analysis was performed by RLS (note that the standard automated test for RLS acquires at least 20 points). The results of this analysis are shown in Figure 9e. The automated analysis of RLS on this type of sample, with only 8 points, was able to detect the three mineral phases present in the mixture (two types of olivine and dolomite). The summary of results is covered in Table 4.

The results of the analysis of sample 1 highlight the importance of the collaborative science between the different instruments: placing the RLS instrument directly on an interesting grain in a matrix of other materials has allowed detecting that material very easy and accurately. Furthermore, due to the inherent characteristics of infrared vs Raman spectroscopy, the analysis with RLS provides a more accurate identification of the mineral phases present in the sample, in comparison with MicrOmega. The analysis of sample 2 again highlights the necessary improvement in terms of science return of the combined science between the different instruments of the ExoMars rover ALD. However, it also stresses the necessity of performing the RLS automated operation. This approach (MICR-RLS collaborative + RLS automated acquisition) is currently foreseen in the rover software capabilities and is the best way to ensure a proper characterization of the sample and the highest scientific return from the operation on Mars.

Conclusions

The ExoMars mission rover presents a unique and unprecedented opportunity to perform combined analysis between complementary techniques on a planetary *in-situ* mission, at the same spot of the same sample. This provides also the opportunity to perform these tasks onboard, without the need of ground intervention. However, in order to guarantee a correct alignment between the different instruments of the rover laboratory, it is necessary to analyze a common pattern to be able to identify the relative positions of the instruments after landing.

The RLS instrument will have two different calibration targets onboard the rover. Both feature a small PET part as calibrant material. Due to engineering constraints, one CT will be used for calibration operations and pre-launch and cruise verifications, while the other will be used for optical health checks during nominal operation. The RLS CT team performed a complete suite of tests for the qualification of PET for the conditions the exploration of

Mars with the ExoMars rover. The PET spectrum also presents several peaks distributed along the spectral range as well as a characteristic background with which it will be possible to verify the health status and check the spectral calibration of the instrument, even at the different operation temperatures expected during the mission.

In order to facilitate the spatial cross-registration of the instruments, especially RLS and MicrOmega, one of the two CTs was modified to include patterns that can be detected by both instruments. These patterns were created by performing mechanical (milling) and molecular modifications (with laser) and will be used to correlate the positions of the instruments. This is key to facilitate the combined science concept onboard ExoMars.

The joint analysis performed by RLS and MicrOmega show how the combined science between the instruments of the rover is of paramount importance in order to increase the scientific return of the mission. However, these joint tests have also shown that the RLS instrument obtains very fruitful results when working in autonomous mode (without indication from other instruments), further complementing the RLS+MicrOmega combined operation. Therefore, the operational approach of the ExoMars has been designed to allow the combination of the MicrOmega-RLS collaborative operation plus an RLS automated acquisition.

Future work should be directed in two different lines. On one hand, performing further tests with the other instruments of the rover (as for example a MicrOmega, RLS and MOMA joint test). On the other, it is well known that the combination of Raman and infrared spectroscopies is very fit given the complementarity in their detection capabilities, so working in joint analytical techniques such as data fusion for improved analytical performances seems to be necessary in order to push the collaboration from a data-acquisition to a data-exploitation perspective.

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479 ***Table 1. SNR values of the Raman spectra obtained from the RLS CT test units before and after the qualification campaign, which included -among other processes- a 150h bakeout at 125ºC and a 120h sterilization process at 115ºC.***

Point	CT3		CT4		CT5	
	Before	After	Before	After	Before	After
1	131	151	100	142	152	139
2	113	129	112	135	146	137
3	103	128	98	124	149	139
4	104	127	119	134	144	140
5	118	134	95	138	127	140
Average	**114**	**134**	**105**	**135**	**144**	**139**

Table 2. SNR values of the Raman spectra obtained from PET after the UV exposure tests. The PET1 exposed face is the upper face of the irradiated PET sample, were the UV radiation hit directly. PET1 non-exposed (shadow) refers to a region of the upper face that was shadowed from the UV radiation. The PET1 non-exposed face (lower face) corresponds to the lower face of the PET1. The PET2 non-exposed sample is the control sample, which was not introduced in the chamber.

Point	PET1 UV exposed face	PET1 non-exposed (shadow)	PET1 non-exposed face (lower face)	PET2 non-exposed sample (control)
1	377	492	534	778
2	210	795	449	885
3	224	-	688	745
4	317	-	792	613
Average	**282**	**644**	**616**	**755**

493 ***Table 3. Targets position and composition from RLS and MicrOmega analyses***
494 ***for sample 1.***

Target name	Position in MicrOmega's frame (x,y)	Composition from MicrOmega data	Position of RLS spot in reference frame (µm)	Composition from RLS data
Target A	Pixel (89,191)	Carbonate mixed with Fe-rich smectite and gypsum	(9925,24065)	Dolomite, cerussite and gypsum
Target B	Pixel (202,165)	Carbonate mixed with Fe-rich and Al-rich smectites and gypsum	(10135,23690)	Dolomite
Target C	Pixel (221,176)	Carbonate mixed with Al-rich smectite and gypsum	(12275,23295)	Dolomite, cerussite and gypsum

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Table 4. Targets position and composition from RLS and MicrOmega analyses for sample 2.

Target name	Position in MicrOmega's frame (x,y) and corresponding position in reference frame	Composition from MicrOmega data	Position of RLS spot in reference frame (µm)	Composition from RLS data
Target A	Pixel (75,150)	Anhydrous carbonate mixed with olivine	(17085,18995)	Dolomite, and two types of olivine (forsterite and Fe-Rich olivine)
Target B	Pixel (140,55)	Anhydrous carbonate mixed with olivine	(15295,17930)	Dolomite and olivine (forsterite)
Target C	Pixel (28,88)	Carbonate with OH or H_2O mixed with olivine	(17385,17620)	Dolomite and forsterite
Target D	Pixel (41,205)	Carbonate with OH or H_2O	(18060,19640)	Dolomite and olivine (forsterite)

Figure 1. PET spectrum (a). RLS calibration targets (b). RLS CT design and configuration, showin how the calibrant (PET, white part) is mechanically fixed to the CT body (c).

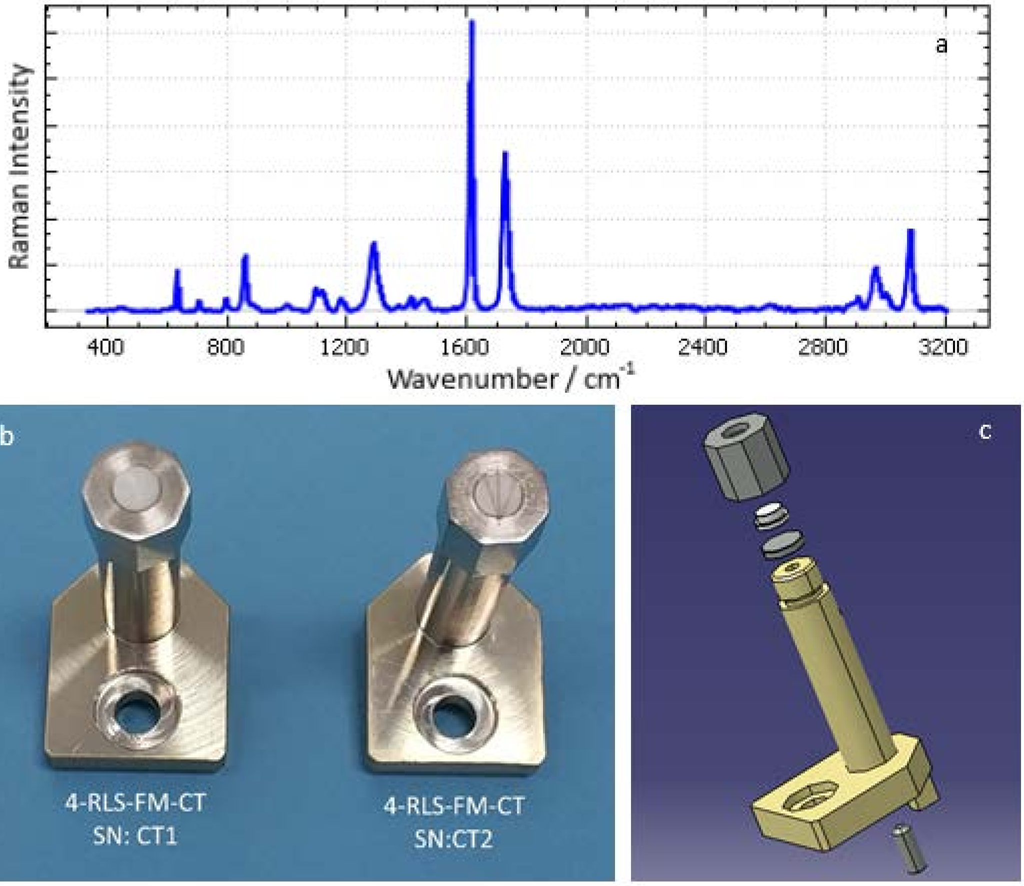


Figure 2. RLS CT with the mechanical and laser-induced patterns.

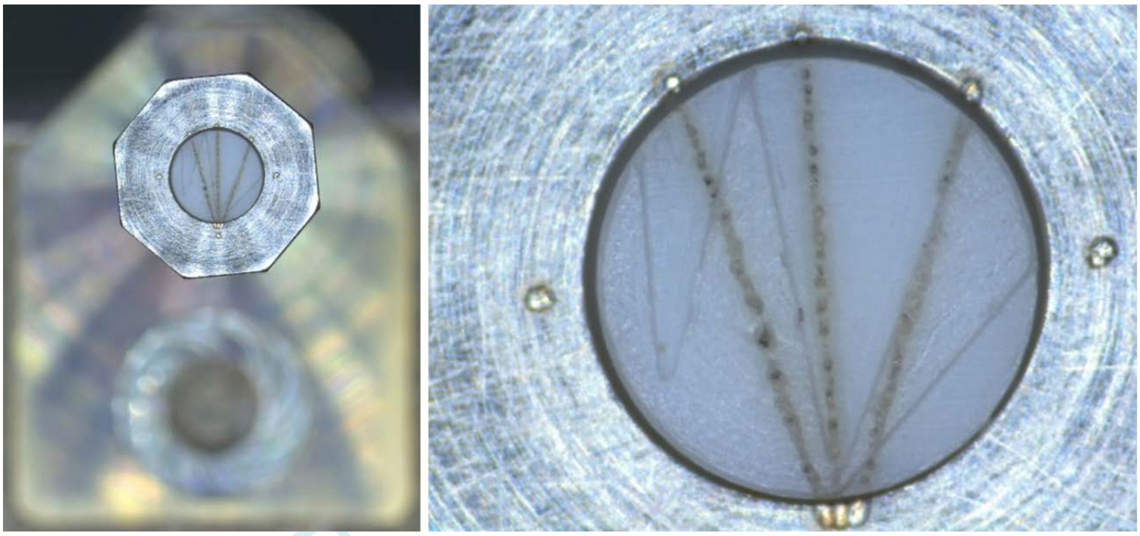


Figure 3. Raman spectra examples on the marked surface(a): PET (blue), laser mark (red), threshold between the PET and the mark (cyan). Detection of a laser line by Raman spectroscopy (b). Detection of the mechanical mark with the RLS autofocus photodiode (c).

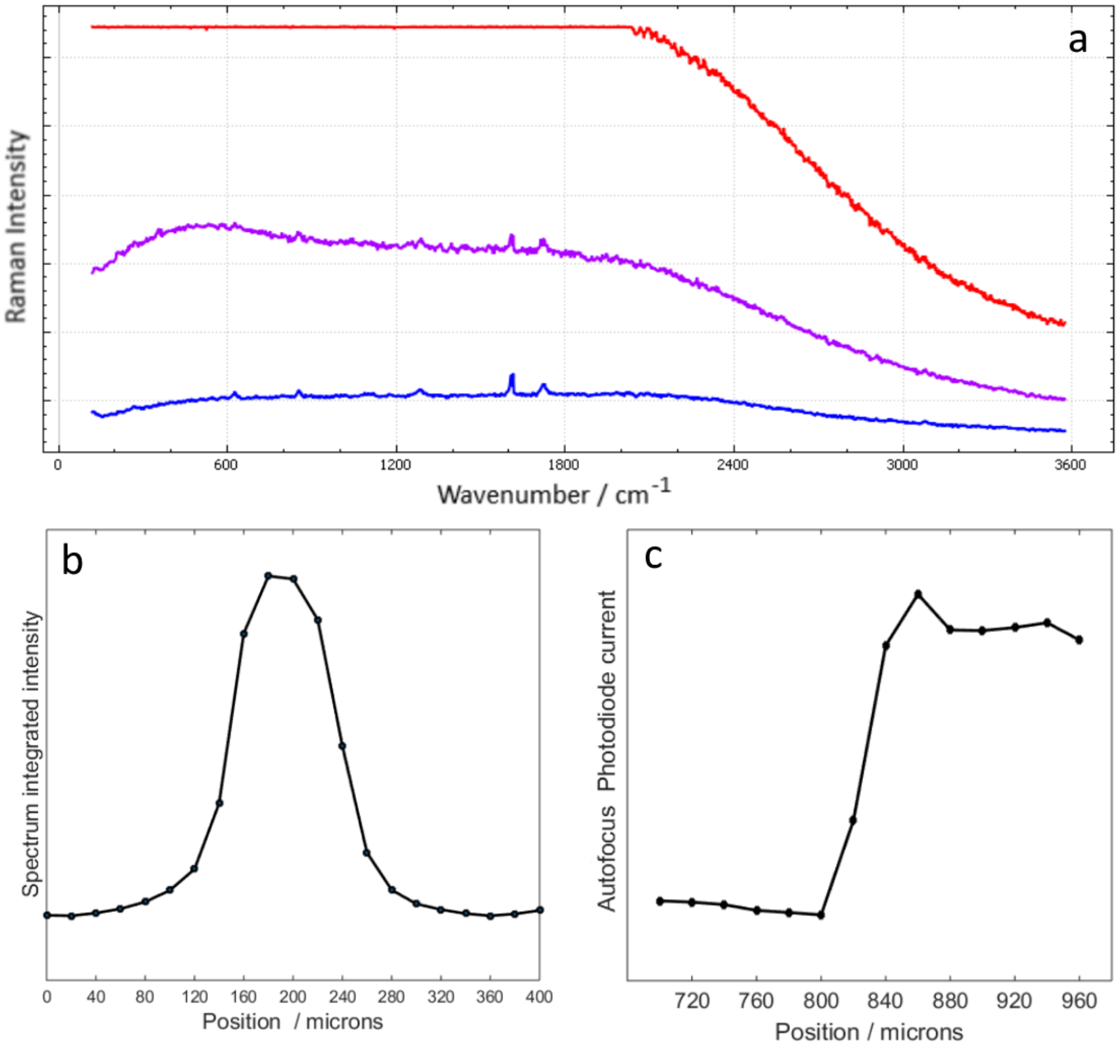
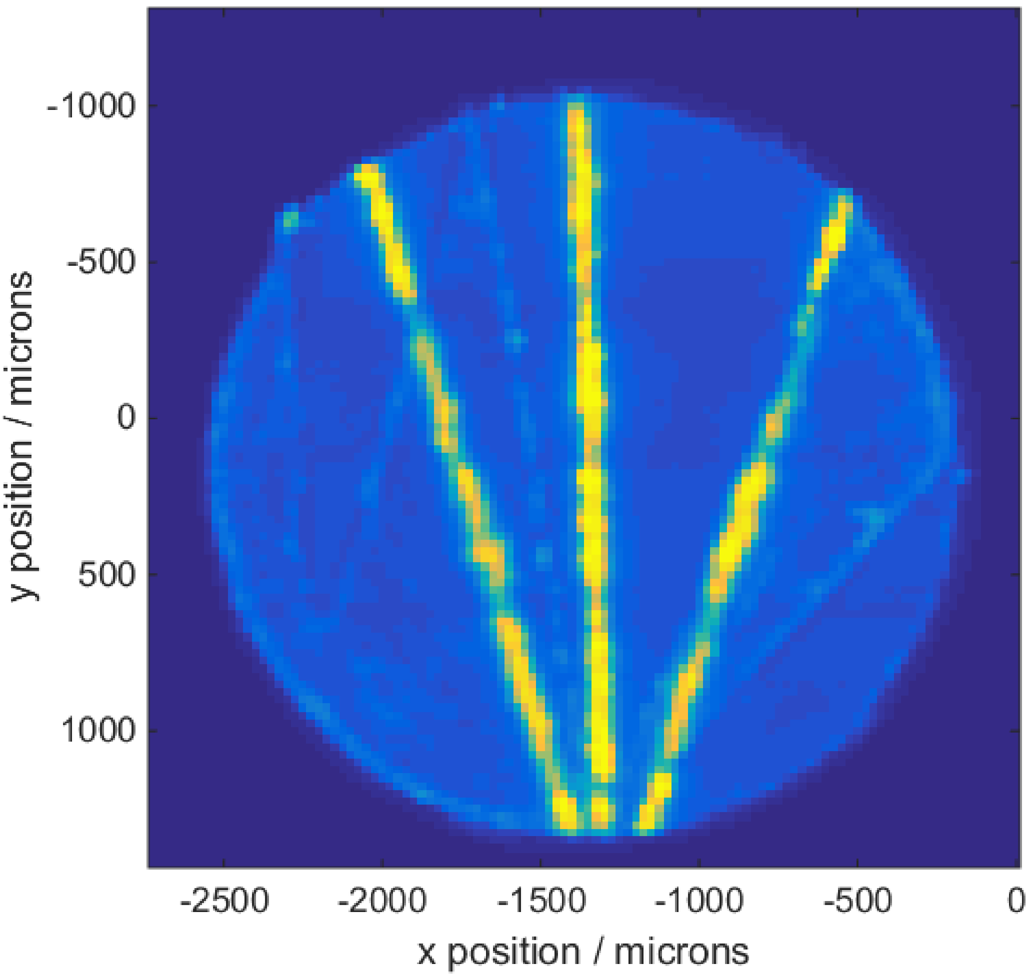


Figure 4. Map of the RLS CT performed with the RLS ExoMars Simulator. Each pixel represents the spectrum integrated intensity. Spatial resolution is 25 microns.



521 ***Figure 5. Partial map of the CT based on the RLS autofocus photodiode***
522 ***intensity values. Black lines represent the borders of the mechanical marks,***
523 ***while the red lines represent the laser marks. Superimposed are the values***
524 ***from the photodiode.***

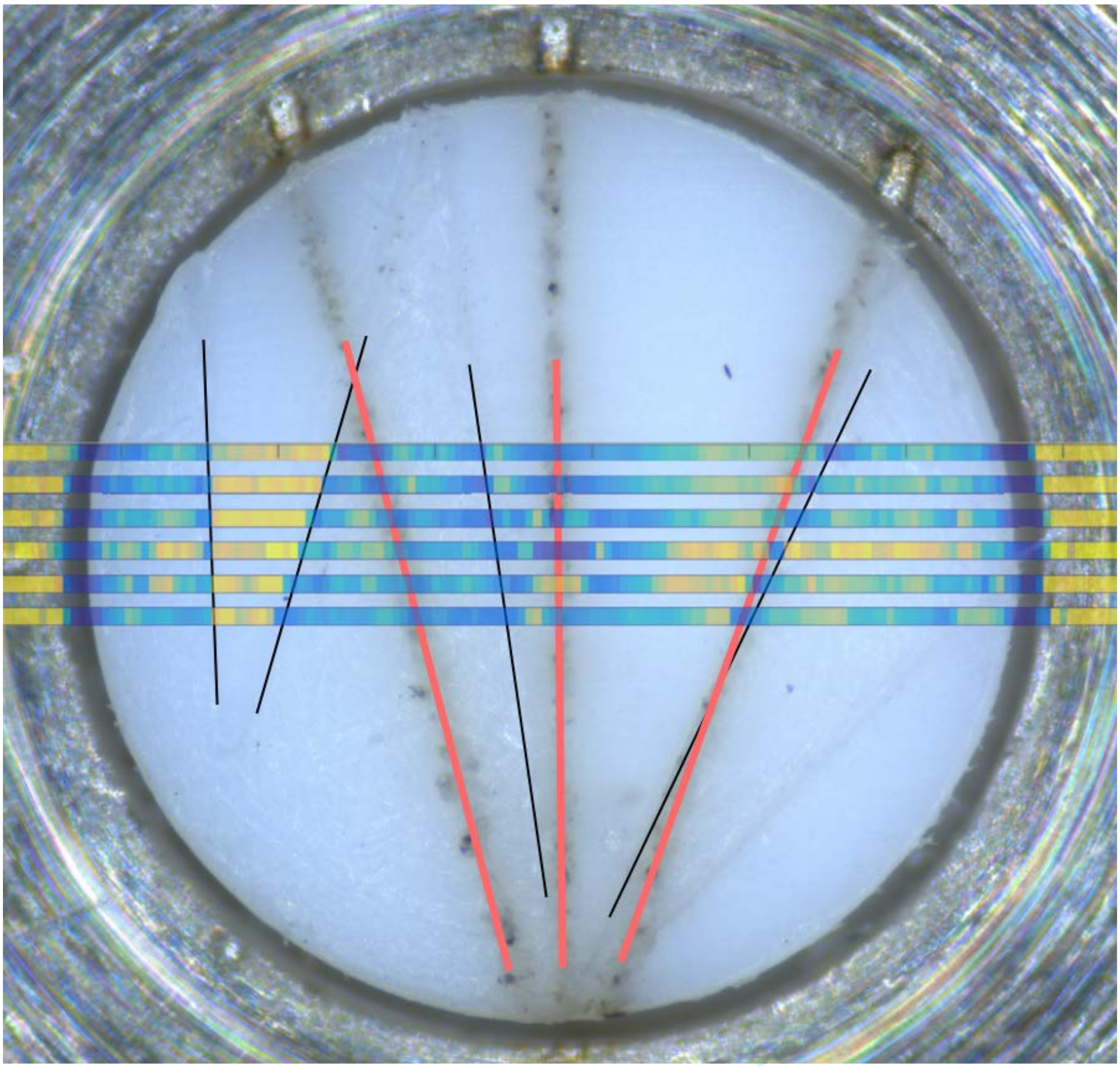


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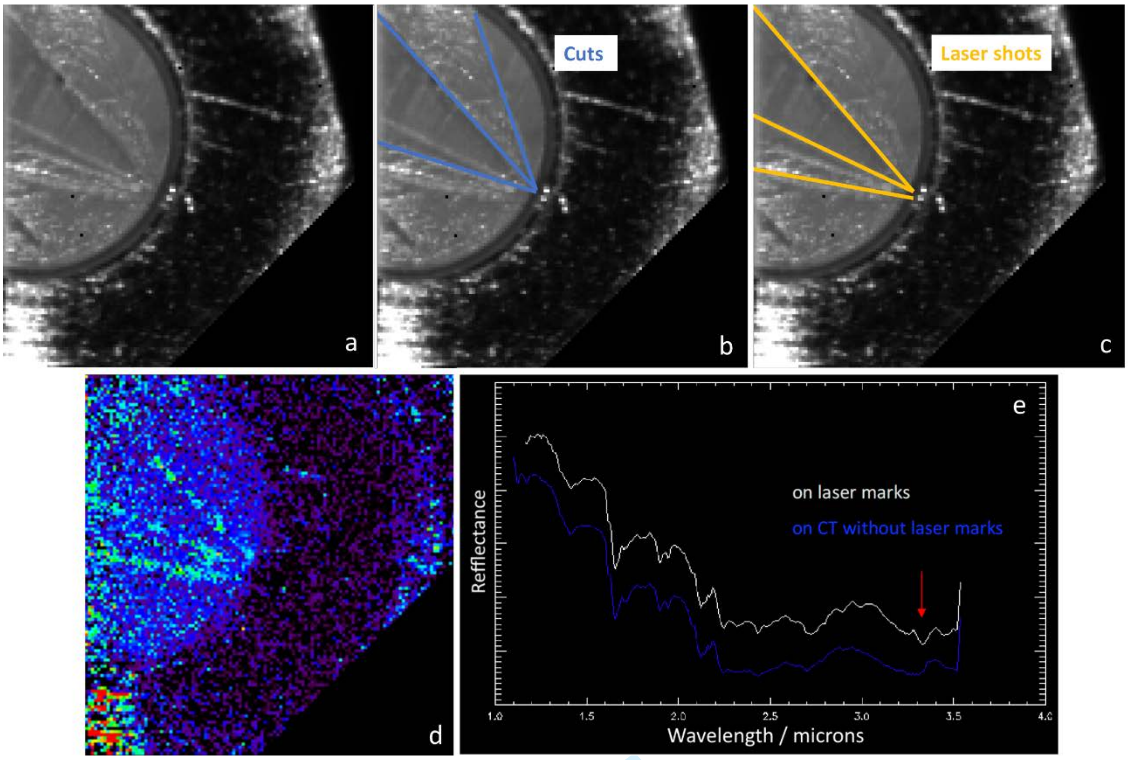
Figure 6. Map of the CT performed with the MicrOmega instrument. The monochromatic image at 1.3 micrometers (a) allows the identification of the mechanical (b) and laser marks (c). The laser lines are also detected based on their spectroscopic response (d, e).



533 ***Figure 7. Mass composition (in mg) of sample 1 (left) and sample 2 (right) used***
534 ***in the RLS MicrOmega joint test.***

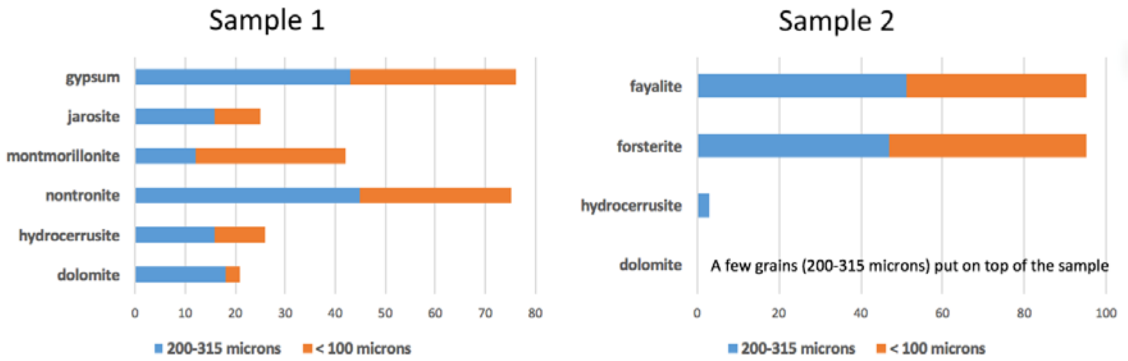


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Figure 8. Sample 1 analysis results. MicrOmega monochromatic image at 1.3 micrometers (a) is used to detect features of interest -in this case, carbonates- (b). Reflectance spectra from MicrOmega data (c). Selection of spectra of the RLS analysis on the targets defined by MicrOmega (d), and from the automatic analysis by RLS (e).

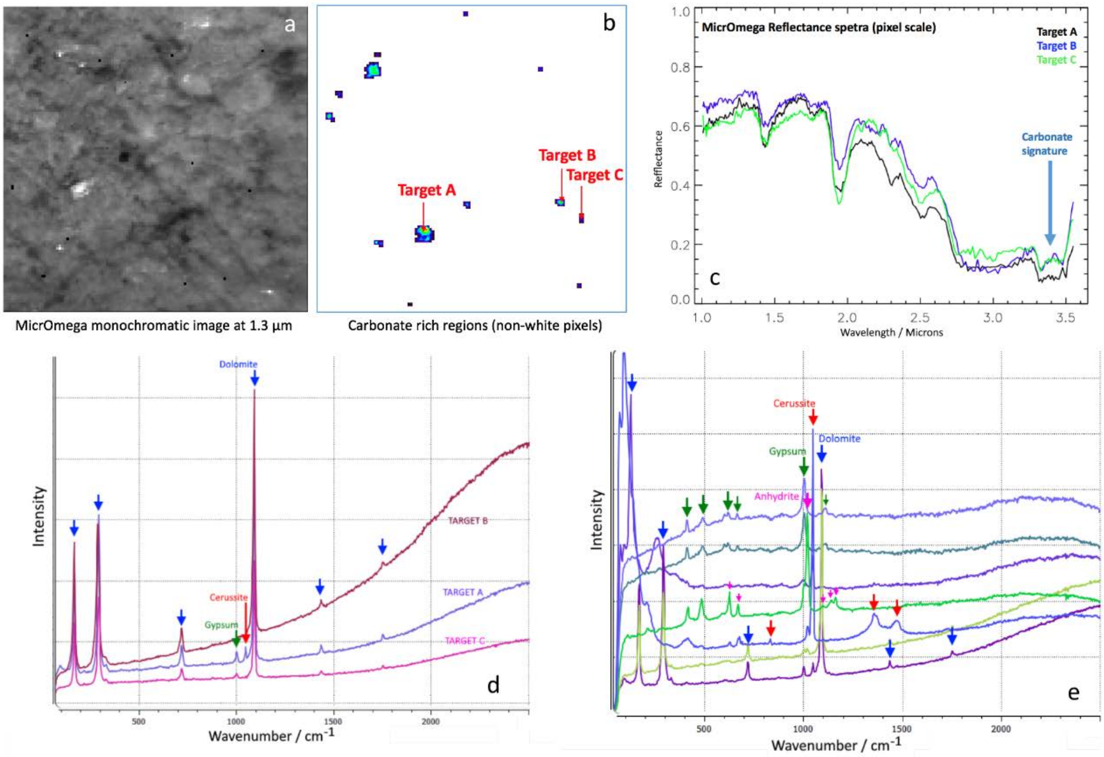

Figure 9. Sample 2 analysis results. MicrOmega monochromatic image at 1.3 micrometers (a) is used to detect features of interest (b). Refflectance spectra from MicrOmega data (c). Selection of spectra of the RLS analysis on the targets defined by MicrOmega (d), and from the automatic analysis by RLS (e).