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# Planetary Terrestrial Analogues Library project: 2. building a laboratory facility for MicrOmega characterization

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ABSTRACT

Multiple spectroscopic techniques have been selected on previous, present and forthcoming missions to explore planetary surfaces in the Solar System. In particular, forthcoming ESA/Roscosmos and NASA missions to the surface of Mars will bring instruments capable of near-infrared (NIR), Raman and Laser Induced Breakdown Spectroscopies to analyze the mineralogy and chemistry of rocks. The PTAL (Planetary Terrestrial Analogues Library) project aims at building a multi-instrument spectral database of a large variety of natural Earth rock samples, including Mars analogues. The NIR hyperspectral microscope MicrOmega was selected to characterize the mineralogy of these analogues within the PTAL project. The instrument model used for the PTAL project is a spare flight model that requires specific care. For the safety of the instrument, and because of the large number of samples in the PTAL library and the requirement to optimize the observational conditions, a dedicated and semi-automated setup was built for the use of the MicrOmega instrument for this project. This paper presents the requirements specified for this setup, the technical solutions that have been selected, their implementation and the performances of the set-up. Sample preparation and operations during sample observations are explained, and a characterization example is presented to briefly illustrate the capabilities of MicrOmega in this set-up. The complete results from the MicrOmega characterizations of the PTAL rock analogues will be presented in a forthcoming paper (Loizeau et al. in prep).

## 1. Introduction

Near InfraRed (NIR) hyperspectral imagers are among the major instruments of many recent and new payloads of planetary space missions. They have the strong advantage of providing mineral and organic information of planetary surfaces with a relatively high speed/high spatial resolution in a non-destructive way. They can be integrated both on orbital missions and on surface platforms, to provide surface compositional information from global surveys to sample microanalyses (e.g. Bibring et al., 2004; Murchie et al., 2007; Pilorget and Bibring, 2013).

During *in situ* exploration missions, mineralogical and organic analyses are strongly strengthen by the combination of multiple spectroscopic and chemical methods including NIR spectroscopy. In this context, the aim of the PTAL project is to build and exploit a multi-instrument spectral database and joint spectral interpretation tools, including NIR and Raman spectroscopy, and Laser Induced Breakdown Spectroscopy (LIBS), on a large number of natural Earth samples characterized by X-Ray Diffraction (Werner et al., 2018). Those samples have been selected to represent a variety of geologic contexts with strong analogies to multiple Martian past aqueous environments. The chosen analysis techniques represent instruments that will be widely onboard future surface exploration missions as best exemplified by the forthcoming ESA/ExoMars Rover and NASA/Mars2020 missions that will combine diverse instruments capable of NIR spectroscopy (SuperCam/Mars 2020, ISEM/ExoMars, Ma-MISS/ExoMars, MicrOmega/ExoMars), Raman spectroscopy (SuperCam/Mars 2020, SHERLOC/Mars 2020, RLS/ExoMars), and LIBS (SuperCam/Mars 2020) (Wiens et al., 2016; Beegle et al., 2015; Vago et al., 2018).

Within the PTAL database, the NIR characterization of the samples is made with both a laboratory point spectrometer of high spectral

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**Table 1**
MicrOmega FS specifications.

| | |
|---|---|
| MicrOmega instantaneous FOV (IFOV) | ≈20 μm × 20 μm |
| MicrOmega FOV | 256 × 256 IFOV (≈5 × 5 $mm^2$) |
| Spectral range | 0.99–3.6 μm + 4 LEDs (LED1: 595 nm, LED2: 643 nm, LED3: 770 nm and LED4: 885 nm) |
| Spectral resolution | 20 cm-1 |
| Focal distance from the base of MicrOmega | 28.7 mm |
| Depth of focus | ±0.1 mm |
| Acquisition duration for one spectral cube | ≈15 min |

resolution (detailed in Lantz et al., 2020), and a flight spare of the MicrOmega ExoMars instrument. MicrOmega is a NIR hyperspectral microscope (Pilorget and Bibring, 2013). MicrOmega illuminates the field of view with monochromatic light at chosen wavelengths selected through an Acousto-Optic Tunable Filter (AOTF) and acquires this way a series of images at many different wavelengths. Earlier versions of MicrOmega have been selected to characterize Phobos on the Russian PhobosGrunt mission (Pilorget et al., 2011) and the surface of the near-Earth asteroid 162,173 Ryugu on the Mascot/Hayabusa-2 lander mission (Bibring et al., 2017a). The model that is used for the PTAL project is the spare flight instrument of the MicrOmega model (hereafter named MicrOmega FS), whose flight model has been integrated on the ExoMars rover Rosalind Franklin (Bibring et al., 2017b).

The use of MicrOmega FS to observe a large number of samples in safe and efficient conditions required the design of a dedicated set-up. After a short description of the MicrOmega instrument (section 2), the paper describes in detail the choices that were made for the final design of a specific set-up for MicrOmega FS (section 3). The operational conditions that were defined for the characterization of the whole PTAL analogue rock collections are presented in sections 4 & 5. The characterization of one PTAL mineral sample is then exemplified (section 6), whereas the results of the characterization of the entire PTAL collection using this facility will be presented in a forthcoming paper (Loizeau et al. in prep).

### 1.1. MicrOmega/ExoMars instrument

The MicrOmega instrument for ExoMars (Bibring et al., 2017b) is a microscope acquiring images with pixels of ~20 × 20 $\mu m^2$ over a 256 × 256 pixels field of view (~5 × 5 $mm^2$). An AOTF enables to illuminate the field of view (FOV) with monochromatic light in the NIR range from ~0.99 to ~3.6 μm with a spectral resolution of 20 cm-1 (equivalent in wavelength to 2 nm at 1 μm and to 26 nm at 3.6 μm). The cooled detector acquires the reflected light at each ~300 wavelengths and builds this way a hyperspectral cube. The NIR observations using the AOTF are completed with four images illuminated with LEDs (Light Emitting Diodes) centered on wavelengths at about 595, 643, 770 and 885 nm (Bibring et al., 2017b). The main characteristics are listed in Table 1.

The spectral range and sampling were selected to enable the identification of major mineral, ice and organic species with a compact and light instrument (168 × 157 × 101 $mm^3$, <2.2 kg).

A typical sequence of images to build a spectral cube is acquired with MicrOmega FS as follows:

- an image is acquired while the FOV is illuminated at a given wavelength,
- a "dark" image is acquired with no illumination of the sample,
- the instrument software calculates the difference between those two images,
- the same operation can be accumulated 1, 4 or 16 times at the same wavelength,
- the same sequence is executed at another wavelength.

While the instrument is designed to operate from −40 °C to 40 °C, better performances are achieved at cold temperatures. At these conditions, the background thermal infrared emission of the instrument is lower, which increases the Signal to Noise Ratio (SNR) (Riu et al., 2018). In addition, operating the instrument at negative temperatures allows to simulate the observation conditions on the Martian surface. The thermal regulation of the instrument within the PTAL set-up has been thus considered as an important aspect of the setup.

For the same reason, it was also chosen to cool-down the samples. Although the systematic subtraction of the "dark" image enables to work with samples at ambient temperature, the detector saturation is reached more rapidly due to the higher thermal emission of the sample. Lowering the temperature, and hence the thermal emission of the sample, enables to acquire data with longer integration time, and hence to increase the SNR.

**Table 2**
Requirements for the set-up.

| | Quantified requirement | Origin of the requirement |
|---|---|---|
| Controlled chamber characteristic | | |
| Operating MicrOmega FS temperature | −15 °C to −20 °C | Performance |
| Sample temperature | < −5 °C | Performance |
| Atmosphere | Dry atmosphere (no frost or condensation on the instrument or sample) | Safety of the instrument |
| Operational requirements | | |
| Number of samples per analysis | 1-8 or more (depending on sample size) | Automatization |
| Duration from ambient to optimal conditions | ≈1 Hour | Duration |
| **Accuracy for the sample positioning** | | |
| Horizontally (X, Y) | <60 μm × 60 μm (≈3 MicrOmega pixels) | Automatization |
| Vertically (Z) | <0.1 mm (MicrOmega depth of focus) | Performance |

## 2. Technical configuration of the PTAL MicrOmega set-up

### 2.1. Requirements

In addition to the previous requirements related to the performances of MicrOmega FS, the other major objective of the set-up was to ease and automatize the characterization of the PTAL samples. This leads to define several environmental and operational requirements listed in Table 2.

The operational and performance related requirements conduct to have both the instrument and the samples in a thermally controlled and dry atmosphere to avoid water frost and condensation. The desired accuracy in the sample positioning implies the use of a precise electronically controlled stage with motions in all three directions.

To ensure protection from dust, in compliance with the nature of the flight model of MicrOmega FS, an additional requirement was made to set MicrOmega FS in a contained environment with respect to the samples.

The requirement for a regulation duration from ambient temperature to optimal temperature of maximum 1 h leads to choose a glove-box equipped with an air-lock to introduce and manipulate the samples. Indeed, if the door of the controlled chamber had to be fully opened each time the samples need to be manipulated, the duration to reach a sufficiently dry environment within the box after each sample change would be too long or require heavy equipment out of scope of the funding budget and oversized with regards to the PTAL objectives.

### 2.2. Design overview

A specific design has been implemented to be compliant with the above requirements. A 3D Computer-Aided Drafting (CAD) view and picture of the final and integrated set-up are shown in Fig. 1. The set-up is composed of three different subsystems:

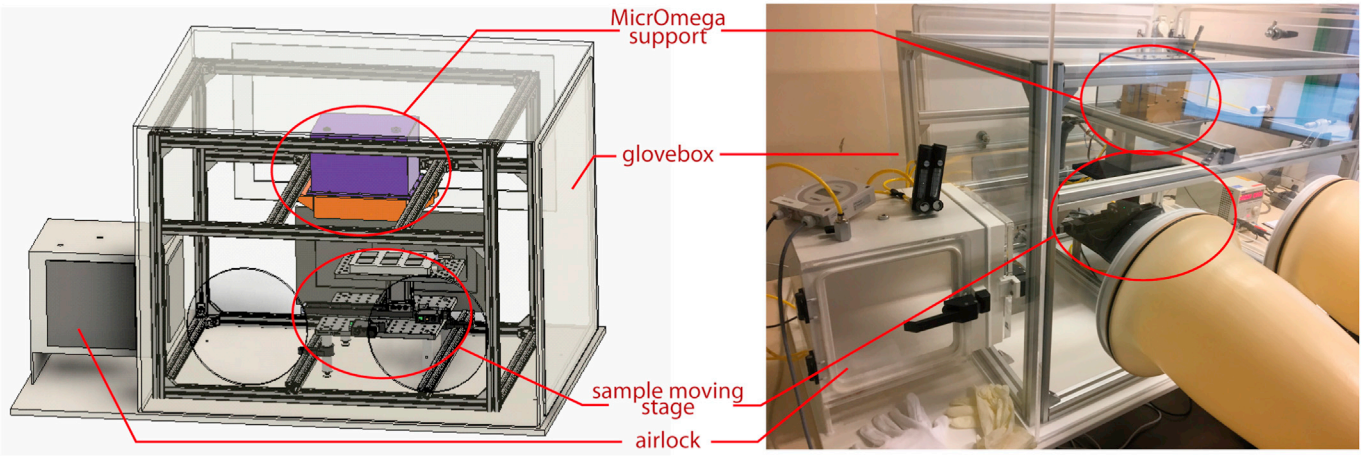


**Fig. 1.** Global CAD view (left) and picture (right) of the set-up. The higher pressure inside the glovebox inflates the gloves.

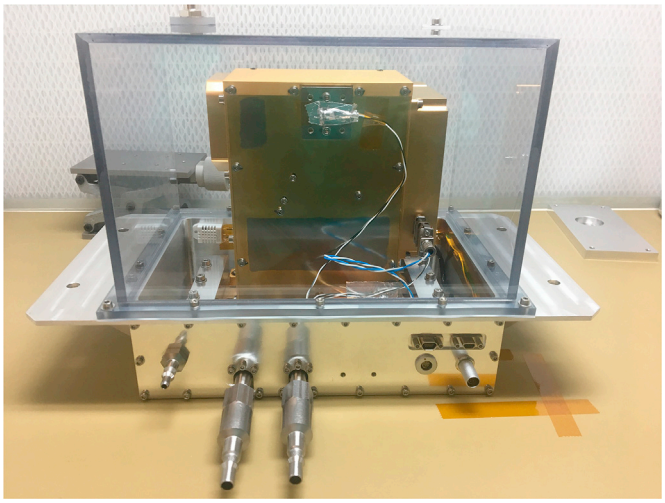

**Fig. 2.** Picture of the MicrOmega support, with MicrOmega FS inside. The feedthroughs visible in the metallic part are set for $N_2$ flushing, cold fluid circulation, and power and electronic connections (from left to right).

- The **MicrOmega support**; it was designed to protect the space instrument from contamination (dust, frost …) and to secure it in a controlled environment. It also provides a cold interface at −25 °C to regulate the temperature of MicrOmega FS.
- The **sample moving stage** is a multi-axis motorized stage that can support multiple samples and deliver them to MicrOmega for characterization. It reduces manipulation and provides accurate positions of the samples in the field of view of the instrument. In addition, it cools down samples to ~ -10 °C.
- The **controlled chamber** is a glovebox filled with dry nitrogen gas with an environment regulation system to protect MicrOmega FS and samples from dust and humidity of the atmosphere.

Those three subsystems are described in more details in the following sections.

### 2.3. MicrOmega support

The MicrOmega support (Fig. 2) is a hermetic box flushed with nitrogen gas, it is designed to protect and handle the instrument and to let a large space below for sample handling within the glovebox. It is the first barrier to protect the instrument from dust and humidity. This part also integrates a cold interface to regulate MicrOmega FS thermally (≈-25 °C). This provides thermal conditions similar to the Martian conditions and reduces the thermal contribution of the instrument to the signal.

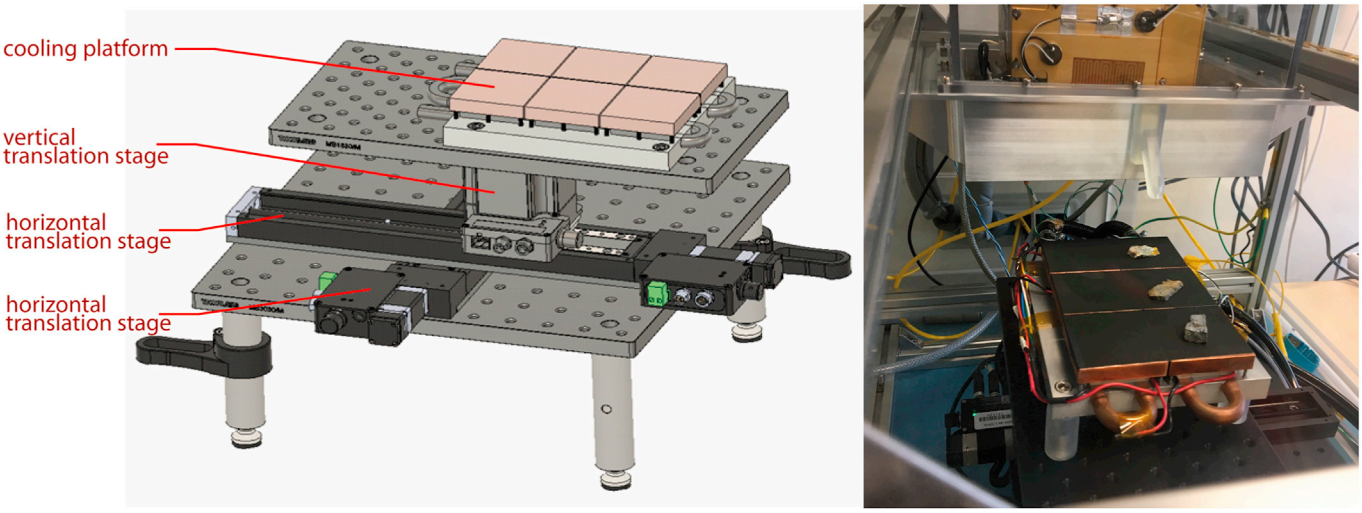


**Fig. 3.** Detailed CAB view (left) and picture (right) of the sample moving stage with the sample cooling platform on top.

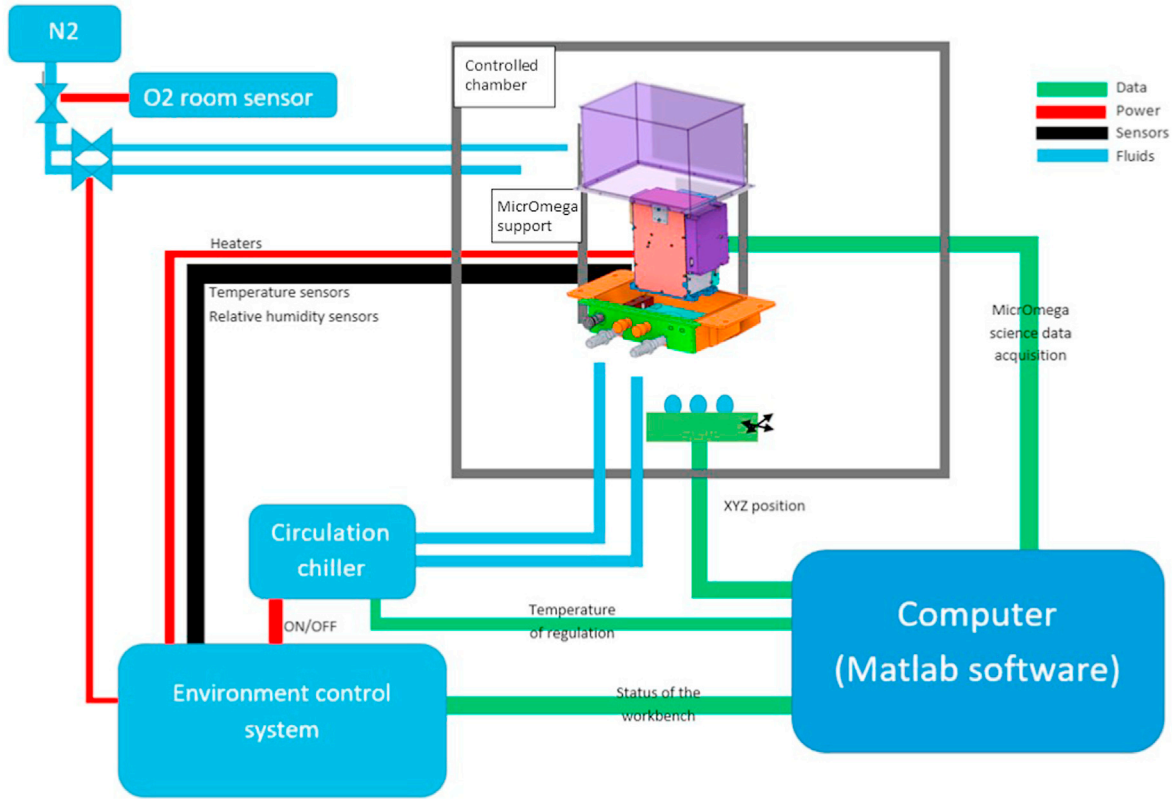


**Fig. 4.** Simplified sketch of power, fluids, sensors and data and command wires controlling MicrOmega and the controlled chamber.

Interfaces between the MicrOmega support and the glovebox enable circulation of $N_2$, cold fluid, power and electronics links.

A sapphire ($Al_2O_3$) window below the box (not visible in Fig. 2) enables the optical observation of the samples by MicrOmega FS while maintaining the controlled atmosphere within the MicrOmega support.

### 2.4. Sample moving stage

The sample moving stage was designed to have a $\approx 10 \times 15$ cm$^2$ cold platform that can translate in the three dimensions (Fig. 3). It can be controlled through computer commands or manually with a joystick.

The accuracy in the horizontal directions is of 60 μm, with a repeatability <3 μm, this gives the possibility to perform multiple contiguous observations with a relative positioning error (<3 μm) smaller than the pixel size (~20 μm), allowing to construct mosaics of observations of a given sample if needed. Moving of a few μm only also gives the possibility to make several observations of the same FOV with a small horizontal offset to achieve spatial oversampling of the FOV. The accuracy in the vertical direction is 35 μm, with a repeatability <1 μm which is more than enough for the depth of focus of MicrOmega FS (100 μm), and could enable focus stacking of images acquired at different distances for uneven rock surfaces.

In addition, a cooling platform is installed at the top of the moving stage. The active cooling is performed by six Thermo-Electric Coolers (TECs) set in two rows of three. The TECs are placed in between six copper plates on the cold side of the TECs on the top and a steel plate with fluid circulation to evacuate the excess heat on the hot side of the TECs below. The top surface of the copper plates is covered with a black thermally conductive tape to minimize possible reflections with the metallic copper plates while ensuring good thermal coupling.

This configuration allows an accurate positioning of the samples in the MicrOmega FS FOV, the observation of multiple samples without any manipulation inside the glovebox, while keeping the samples at a cold (~-10 °C) and stable temperature. Once all samples are loaded on the top of the platform, and observation positions are selected, the sample moving stage can operate automatically and make multi-dimensional acquisitions on each of them.

### 2.5. Controlled chamber

The controlled chamber is the large hermetic glovebox flushed with $N_2$ with an airlock on the left side (see Fig. 1). Thanks to two gloves, the operator can manipulate samples when they are inside the chamber. The controlled chamber has been designed large enough to facilitate manipulation of the samples and to set them on the top of the platform, while leaving space for potential other instruments that might be installed together with MicrOmega in the future. The airlock is flushed with $N_2$ on demand; it enables to introduce samples and tools in the glovebox without introducing humidity in the main chamber. $N_2$ was chosen for practical reasons: the room where the PTAL set-up is installed was already supplied in clean $N_2$, and potential leaks of other gases like $CO_2$ would have been dangerous for the operator. An environment regulation system controls the temperature and humidity permanently at several locations in the MicrOmega support and glovebox to regulate the $N_2$ flux to ensure that no frost is possible at any time on the instrument or samples. The controlled chamber acts hence as a second barrier to ensure the safety of MicrOmega FS.

### 2.6. Other safety set-ups

In addition to the MicrOmega support and controlled chamber, other hardware were installed for the safety of the instrument. An ionizing blower is located inside the controlled chamber, oriented towards the MicrOmega support, to avoid the accumulation of static charges in the structure. The entire structure is also connected to a metal braid connected to ground. This avoids any electrostatic discharge to MicrOmega

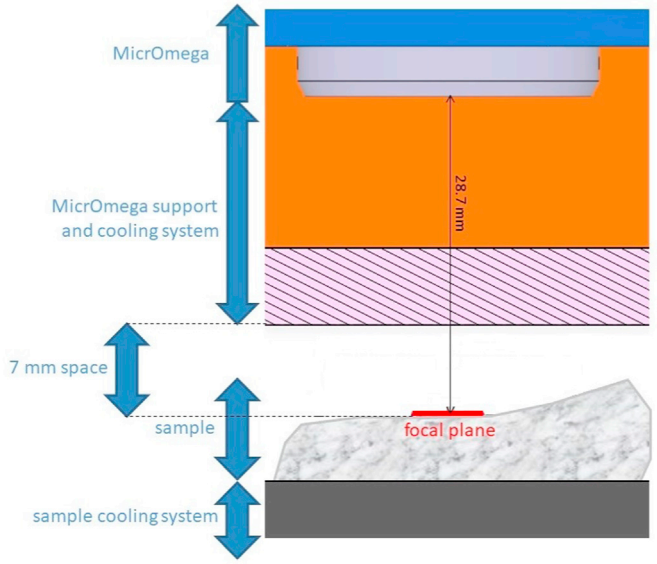


**Fig. 5.** Schematic close-up section showing the distances between the MicrOmega aperture, the MicrOmega support and the sample.

FS. Also, in case of an unlikely sudden breach in the two hermetic chambers (the controlled chamber and the MicrOmega support), heaters have been set on the surface of MicrOmega FS to bring it rapidly to ambient temperature to avoid any potential frost or condensation to form on and inside the instrument.

An $O_2$ sensor has also been set in the room to ensure the safety of the operators, the $N_2$ supply can be automatically turned off.

### 2.7. Fluids, power, and data interfaces

The controlled chamber, with MicrOmega FS and the stage, need several power supplies, fluids circulation systems, sensors, and data and command harnesses. The simplified sketch (Fig. 4) illustrates the architecture of the main fluids and electrical connections, to control the system and "constitute" the safety rack for MicrOmega FS.

Feedthroughs are located at the back of the glovebox and at the back of the MicrOmega support for all wires and fluids to go in and out of the boxes.

Power supplies (not all represented) are needed inside the controlled chamber for MicrOmega FS, for the moving stage, for the security heaters, for the TECs and for the ionizing blower. Computer and electronically controlled switches trigger the different power supplies.

$N_2$ hoses blow inside the glovebox, the MicrOmega support, and the airlock. Outlets are also present and connected to a pump to evacuate the air and humidity from the workbench. Electronic valves control the $N_2$ fluxes.

The chiller fluid goes through the glovebox directly to the cold interface inside the MicrOmega support. The chiller is computer controlled. Another fluid runs through the sample cooling system on top of the sample moving system to evacuate excess heat from the TECs (not represented in Fig. 4).

Temperature and humidity sensors are located inside the glovebox, in the MicrOmega support and in the airlock. Additional temperature sensors are also located inside MicrOmega FS. All those atmosphere data can be checked and recorded through the workbench computer.

Finally, command and data harnesses are connected to MicrOmega and to the stage to control observations and stage translations and receive data.

The environment control system, the circulation chiller and the stage communicate by serial communication with the computer and the Matlab software. MicrOmega FS communicates through a SpaceWire to USB adaptor, also connected to the Matlab software. A safety rack is also directly controlled by the environment control system to avoid any problem due to potential computer bugs.

The entire electric system is plugged to an uninterruptible power supply to avoid any short power-cut or to shut down the systems in case of minute-long power-cut.

**Table 3**
List of steps to operate a MicrOmega measurement within the PTAL set-up.

| Actions | Duration | Comments |
|---|---|---|
| Chiller On | >4 h | Switched on the day before measurements |
| Introduction of samples inside the glovebox | ~2 min | |
| Opening of chiller fluid circulation for MicrOmega cooling | ~1 h | Slow cooling to avoid thermal stress |
| TECs On for sample cooling | ~20 min | Simultaneously to step above |
| Sample pre-positioning | ~1 min per observation | Simultaneously to step above |
| MicrOmega On | ~8 min | |
| Accurate sample positioning | ~1 min | |
| MicrOmega observation | 15–25 min | Duration depends on chosen integration time |
| Move to next sample position and accurate positioning | ~2 min | |
| MicrOmega observation | 15–25 min | |
| Change of position and observation until completion of the set of samples | | |

## 3. Sample preparation for MicrOmega analysis

The MicrOmega FS optical performances combined to the bench setup characteristics imply that the focal plane is very close to the base of the MicrOmega support. The distance between the base of MicrOmega FS and the focal plane is 28.7 mm, but the presence of the cold interface and MicrOmega support limits the distance to ~7 mm between the base of the MicrOmega support and the focal plane (Fig. 5). In addition, the depth-of-focus of MicrOmega FS is only 0.1 mm. It is thus preferable that the observed samples have relatively flat top surfaces to avoid out-of-focus sample areas due to the geometry of the sample: over the whole sample, difference in height should be $< 7$ mm; and over the chosen FOV, difference in height should not exceed 0.1 mm if we want the whole FOV to be in focus. This can be obtained by choosing samples with a relatively flat surface or by cutting a face of the sample. However, parts of the FOV are often slightly out-of-focus, but nevertheless the hyperspectral cube contains useful spectral data.

As previously stated, it was decided to cool down the sample to improve the quality of the data and to simulate Mars conditions. The efficiency of the sample cooling system depends both on the contact between the sample and the cooling system, and on the thickness of the sample as the sample is cooled down from bottom to top. Therefore, thin samples with a very flat bottom surface are favored to facilitate the thermal exchange, while sand or powder samples can be easily presented as flat patches of sand.

As all rocks have different mechanical properties, it was not possible to produce PTAL samples with identical geometries for all rocks, but it was decided to produce samples with thickness <10 mm, a bottom surface as flat as possible (sawed or abraded depending on the rock), a top surface with a relief $< 5$ mm, and sizes $> 10$ mm $\times$ 10 mm. From the 94 samples of the PTAL library, 8 bulk rocks were too small or too fragile to be prepared following this method. It was then decided to observe only the powders prepared from these rocks. For these cases, the material is placed in a small gold-coated copper container (5 mm thick with a cylinder well of 20 mm radius and 2.5 mm depth) specifically procured.

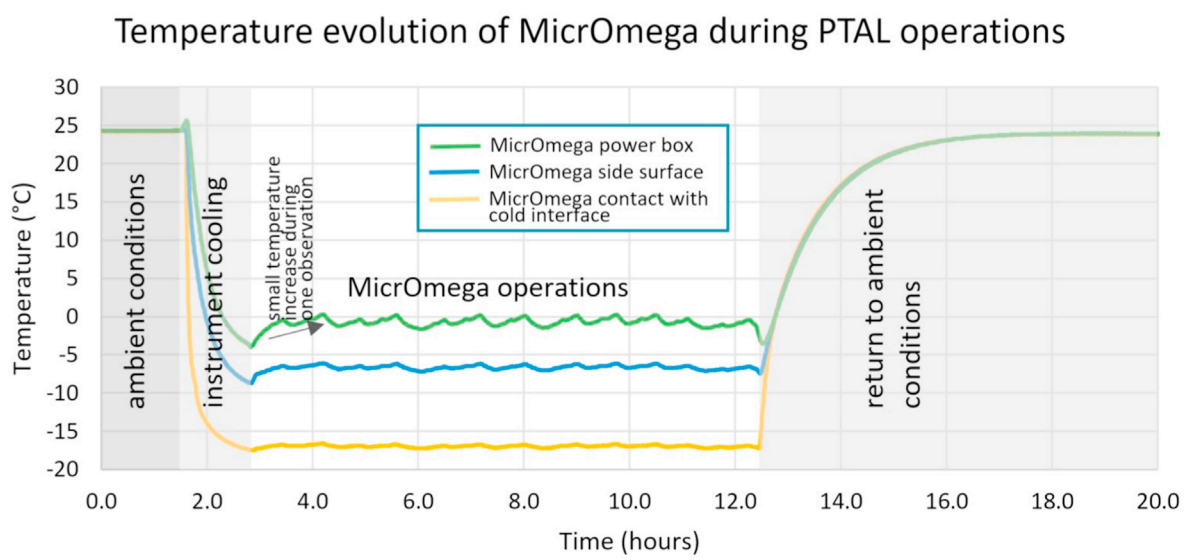


**Fig. 6.** Temperature evolution of a few points on the surface of MicrOmega during PTAL operations. Temperature variations during MicrOmega observations are limited to <3 °C in the PTAL set-up.

## 4. Measurement protocol

Table 3 lists the different operational steps for acquiring a spectral cube of a set of samples. The following sections describes these steps.

### 4.1. Turning on the set-up

Operation usually start with a controlled chamber flushed with $N_2$ at 0% humidity as measured by the sensors inside the chamber (this takes ~24 h but can be prepared well in advance), and a cold chiller (set to −30 °C, it takes about 4–5 h to reach this temperature), while MicrOmega is at room temperature.

The first step is to cool down the MicrOmega cold interface to a stable temperature at ~ -30 °C, which brings MicrOmega FS to a stable temperature after ~1 h.

Meanwhile, a set of samples are introduced inside the controlled chamber to be stored in a dry atmosphere. There is enough room in the controlled chamber to store samples on the floor of the chamber in addition to the sample moving stage.

Also during this time, the TECs for the sample cooling are switched on to bring the samples to a stable temperature. This takes ~20 min.

When MicrOmega FS has reached a stable temperature, it can be switched on, which takes ~8 min.

### 4.2. Sample observations preparation

The geometry of the set-up makes it impossible to see directly the samples when they are under the MicrOmega support, but "pre-positioning" of regions of interest on the samples can be decided by first moving the stage under a pin with the joystick. The computer automatically calculates the stage translation needed to bring this "pre-positioning" point in the FOV and focal plane of MicrOmega FS.

MicrOmega FS can acquire images at a rate of several images per second, and hence can be used as a preview video camera. This capability is used to determine a more accurate position for the observation, as the first step using the pin is not accurate enough, particularly in term of focus distance.

### 4.3. MicrOmega FS observation

Once a sample is at the desired position under MicrOmega FS (right horizontal position and right vertical position for the focus), acquisition of a hyperspectral cube can be started. The last choice is to define the integration time of the observation that shall depend on the temperature and albedo of the region of interest.

Once the first observation is made, the sample moving stage automatically moves to the second position, and a new MicrOmega observation script is started. This operation is made for as many positions as needed on the stage.

When all observations have been made, the samples can be replaced on the stage by another set, and new positions can be determined while the samples are cooling down.

### 4.4. Calibration targets observations

Radiometric and spectral calibration of the spectral cubes are performed using different calibration targets (from Labsphere) with well-known characteristics: a Spectralon-99% and an Infragold for radiometric calibration, and a Spectralon-MCWCS (Multi-Component Wavelengths Calibration Standards) for the spectral calibration (Riu et al., 2018). Specifically, the Infragold has a flat spectrum in almost the entire NIR spectral domain of MicrOmega FS. However, the surface of this calibration target is highly heterogeneous and not lambertian, so the Infragold is only applied to determine the average radiometric response of MicrOmega FS.

The Spectralon-99% that has a more lambertian and very homogeneous surface, is then used to determine the relative response from one pixel to another across the FOV. The Spectralon-MCWCS has a large number of weak spectral absorption bands at known wavelengths. It is thus well adapted to calibrate the spectral response of the AOTF with respect to the applied frequency.

The radiometric and spectral response of MicrOmega FS depends on the temperature of the instrument. Hence, the calibration targets have to be observed at similar conditions to those of sample observations.

## 5. Instrument and set-up performances

### 5.1. Instrument and set-up behavior

During each MicrOmega FS observation, various temperatures acquired by the instrument thermal sensors are recorded. Fig. 6 shows the temperature evolution of three thermal probes set on three different locations on the exterior surface of MicrOmega. The instrument reaches its operational temperature in about 1H, and the temperature at the cold

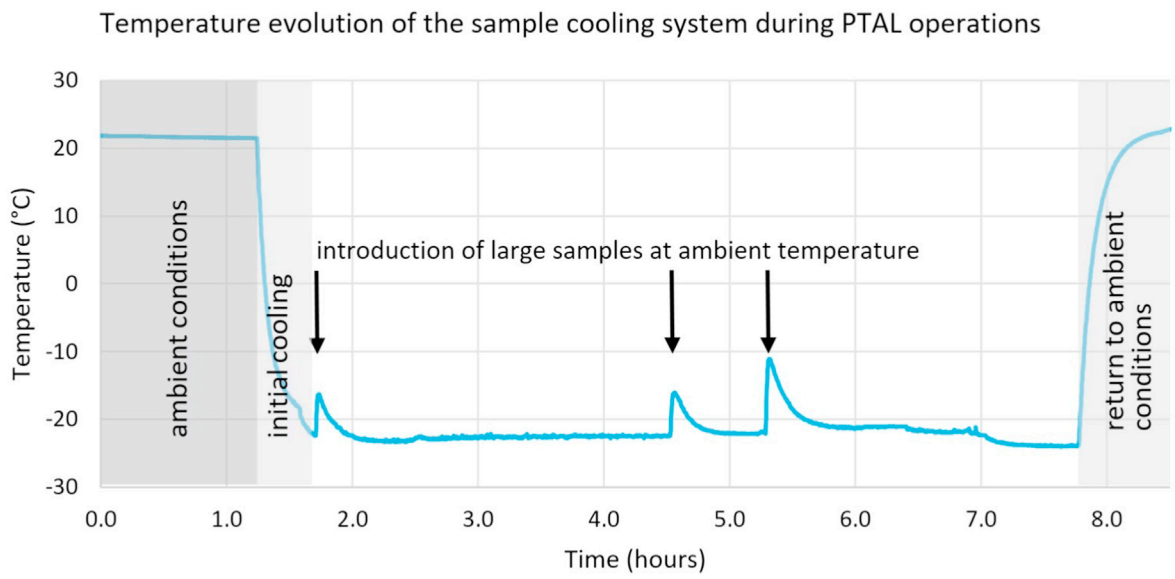


**Fig. 7.** Temperature evolution of the sample cooling system during PTAL observations. The temperature varies mainly when new large samples are set on the platform.

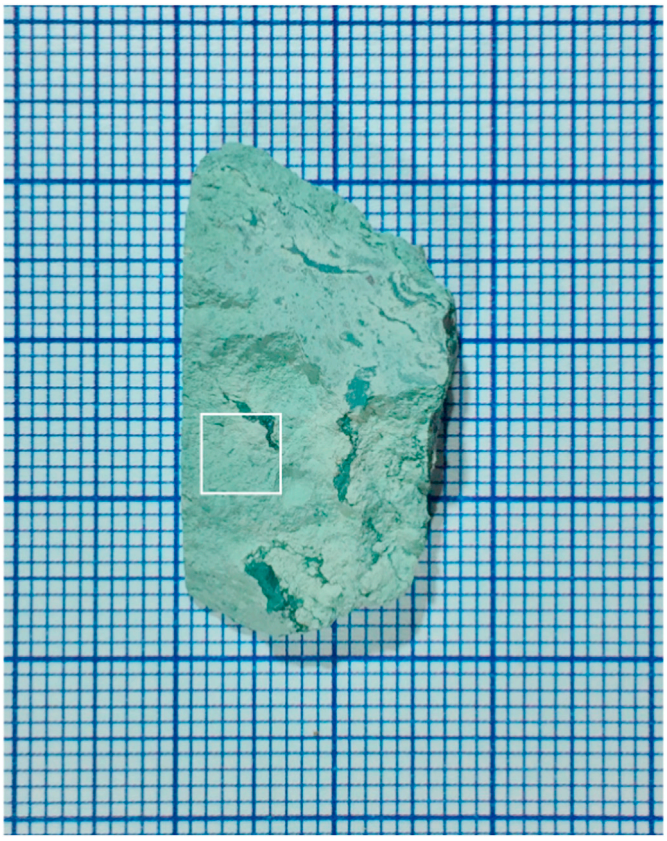

**Fig. 8.** Picture of the sample (TF16-0028) observed in the next figure, the location of the MicrOmega observation is indicated with the white box. The slice of rock was set on millimeter paper for scale, it is about 32 mm × 18 mm, and <8 mm thick.

interface (in yellow) stays stable during the observations. In addition, thermal probes are also installed inside the MicrOmega body. The most critical temperatures to monitor for validating high-quality acquisition are those of the detector regulated by an internal cryocooler, and those of the optical components and AOTF, which are regulated by thermal conductance with the MicrOmega cold interface in the PTAL set-up. During a typical observation campaign day (8–13 samples per day, i.e. 10-11 h of operations), the sensor located closest to the optical components indicates that the temperature of the MicrOmega optical head never varies more than 2 °C, while the AOTF temperature varies by less than 3 °C. These temperature variations are acceptable to ensure the validity of the calibration during the whole campaign slot. Higher temperature variations would still produce valid data, as the thermal background is subtracted for each image, but a more complex data reduction would then be needed.

During the operations, a sensor also records the temperature of the sample cooling platform (Fig. 7). Its temperature can rise up to 10 °C when new samples are introduced, but goes back to equilibrium around −23 °C after 10–15 min. The temperature never varies more than 1 °C during a hyperspectral cube acquisition. Although higher temperature variation of the sample would be acceptable, this temperature stability ensures a stable thermal background, meaning that the detector saturation will never be reached.

The effect of the cooling systems can be evaluated. Cooling down the instrument with the PTAL MicrOmega cold interface at ~ -15 °C lowers the thermal flux by ~30% with respect to the instrument operating at ambient temperature with samples at ambient temperature. When samples are cooled down to ~ -20 °C, the thermal flux lowers by ~65%. Lowering the instrument temperature removes a part of the thermal background issued from the instrument, and if this thermal background is already low due to low sample temperature, then the relative effect is even higher.

During the observation campaign, the humidity remained at 0.0%, even after inserting or removing samples from the glovebox through the airlock.

### 5.2. *Example of a hyperspectral cube*

We provide a first example of a MicrOmega FS hyperspectral cube made with the PTAL MicrOmega set-up. The analyzed piece of rock coming from the PTAL collection is shown in Fig. 8, and the MicrOmega FS observation in Fig. 9. The sample name is TF16-0028 and was collected in Tenerife, Canary Islands, Spain (see Dypvik et al. to be submitted, for complete sample description). Data were calibrated according to the procedure described in section 5.4.

This example shows comparison with NIR spectrum of crushed

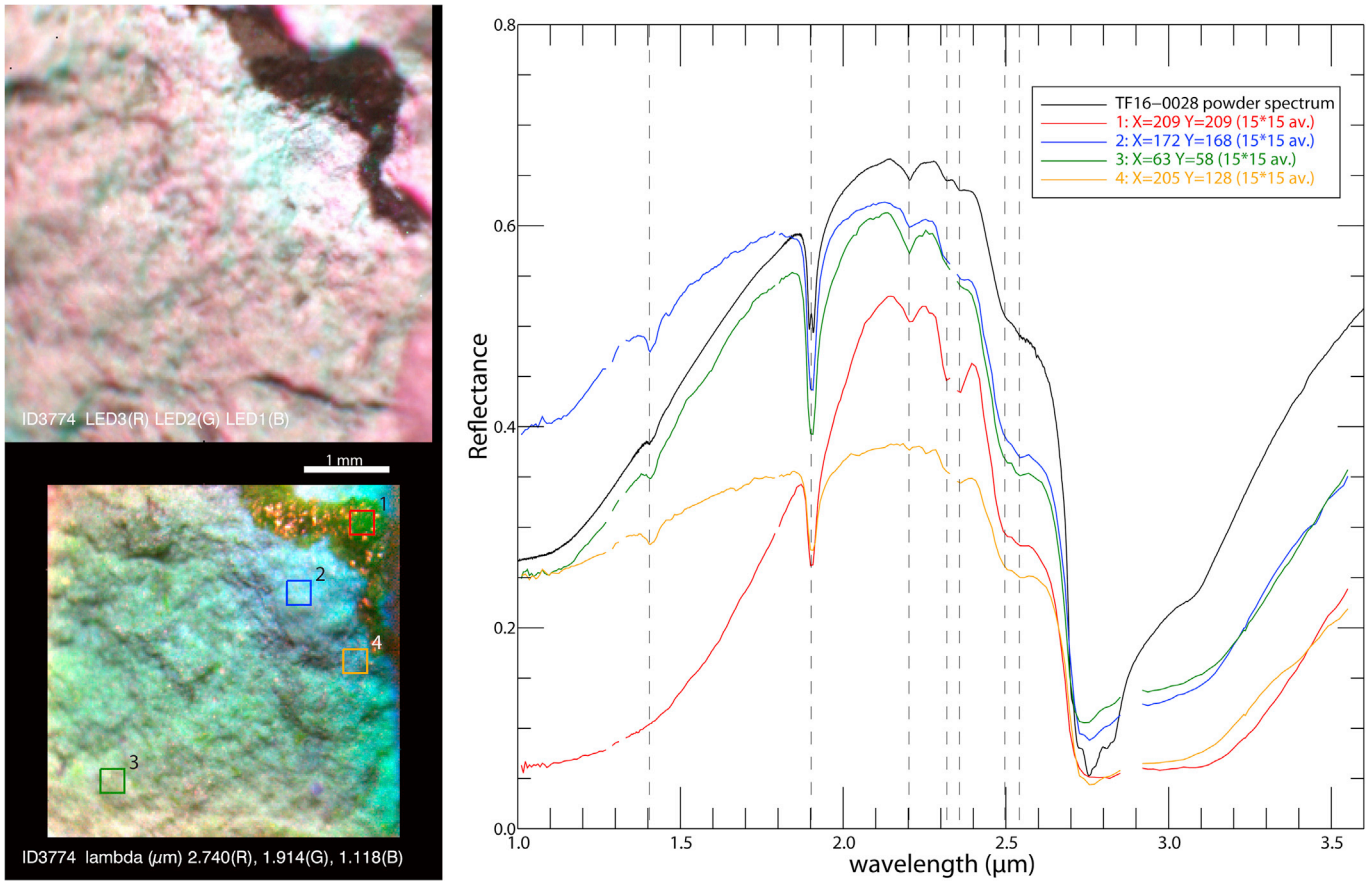


**Fig. 9.** Example of images and spectra from a MicrOmega observation using the PTAL set-up. Top-left is a RGB image from the MicrOmega LEDs (see Table 1). Bottom-left is an RGB IR image with AOTF illumination at three different wavelengths. Right are a spectrum of the crushed powder sample (in black, see Lantz et al., 2020, for more detail) and four spectra (in colors) from the MicrOmega FS observation, each of them being the average of 15 by 15 pixels at the locations indicated by the corresponding color boxes on the RGB IR image (bottom-left). Here are present Al-rich phyllosilicates (spectra 2–4) with the additional presence of probable chlorite (spectrum 1 in red). Further spectral interpretation including high level data products (mineral maps) will be presented in a forthcoming paper (Loizeau et al. in preparation). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

powder from the same rock (see Lantz et al., 2020, for more details about the crushed powder NIR spectral analysis). MicrOmega FS spectra show some variety in the spectral shape across the FOV, here for example in terms of slope between 1.0 and 2.0 μm, and of strong depth variation of absorption bands at 2.2 μm and 2.35 μm. The average signal-to-noise ratio for this observation reaches ~200 for single pixels, but is estimated well above 1000 for 15 × 15 pixels averages like those in spectra of Fig. 8. In this example, noise was evaluated pixel by pixel by subtracting the pixel spectrum by a smoothed pixel spectrum.

### 5.3. Lessons learned

This observation campaign let us confirm that: 1- the instrument can be safely controlled and cooled down in the PTAL set-up with no formation of frost or condensation; 2- with the sample moving stage, the operator can easily set and observe several samples and go through each of those samples with an excellent position accuracy and image quality; 3- transferring material and samples through the airlock does not alter the atmospheric conditions within the glovebox; 4- the acquired data are of high quality allowing to constrain the mineral composition of samples at the microscopic scale.

The totality of the 94 PTAL rock and sand samples have been observed thanks to this set-up in a semi-automatic way during a dedicated campaign. A forthcoming paper (Loizeau et al. in prep) will detail the sampled characterizations and derived products that shall populate the PTAL data base.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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