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MICROMEGA IR: A NEW INFRARED HYPERSPECTRAL IMAGING MICROSCOPE FOR IN SITU ANALYSIS

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Abstract

MicrOmega IR is an ultra miniaturized Near Infrared hyperspectral microscope for *in situ* analysis of samples. It is designed to be implemented on board space planetary vehicles (lander and/or rovers). It acquires images of samples typically some 5 mm in width with a spatial sampling of 20 µm. On each pixel, MicrOmega acquires the spectrum in the spectral range 0.9 – 2.6 µm, with a possibility to extend the sensibility up to 4 µm. The spectrum will be measured in up to 300 contiguous spectral channels (600 in the extended range): given the diagnostic spectral features present in this domain, it provides the composition of each spatially resolved constituent. MicrOmega has thus the potential to identify: minerals, such as pyroxene and olivine, ferric oxides, hydrated phases such as phyllosilicates, sulfates and carbonates, ices and organics. The composition of the various phases within a given sample is a critical record of its formation and evolution. Coupled to the mapping information, it provides unique clues to describe the history of the parent body. In particular, the capability to identify hydrated grains and to characterize their adjacent phases has a huge potential in the search for potential bio-relics in Martian samples.

This purely non destructive characterization enables further analyses (e.g. through mass spectrometry) to be performed, and/or to contribute to sample selection to return to Earth.
MicrOmega IR is coupled to a visible microscope: MicrOmega VIS. Thus, the MicrOmega instrument is developed by an international consortium: IAS (Orsay, France), LESIA (Meudon, France), CBM (Orléans, France), University Of Bern (Bern, Switzerland), IKI (Moscow, Russia). This instrument (MicrOmega IR, MicrOmega VIS and the electronics) is selected for the ESA Exomars mission (launch scheduled for 2013). MicrOmega IR will be used in a reduced spectral range (0.9 – 2.6 µm), due to power, mass and thermal constraints: however, most minerals and other constituents have diagnostic spectral signature in this range.

A full demonstrator model of ExoMars/MicrOmega IR has been assembled at IAS and we will present the design and the experimental results.

1. Introduction

The visible/near-infrared imaging spectrometer OMEGA [1] on the Mars Express mission (ESA), coupled to the NASA Martian Exploration Rover [2], has provided a great change in our vision of Mars [3, 4]. In the near future, we will see a new generation of space probes that will land on Mars, will do some sample in situ analysis or will select interesting ones to return to Earth.

In this context, we are developing at IAS an hyperspectral microscopic imager, MicrOmega IR [5, 6]. This instrument will acquire in situ reflectance spectra of Martian samples, at a scale of the grain size (spatial sampling of 20 µm per pixel), in a non destructive way. It will work in the spectral range 0.9 to 4 µm. MicrOmega will illuminate 5 mm-sized sample sequentially in 600 contiguous wavelengh channels, and will take an image on a matrix detector for each channel. In this way, we get an 'Image Cube' in which the full spectrum of the viewed area is acquired in each pixel. This will enable us to retrieve the composition of the different phases since each mineral exhibits a unique signature in the near-infrared through specific absorption bands.
This non destructive analysis is a good way to select interesting samples for a sample return mission to Earth or for further in situ analysis. This composition enables us to get new clues about the formation and the evolution of Mars.
MicrOmega is based on the development done for the Rosetta/CIVA MI instrument. In order to adapt this design to the environment of Mars, we decided to replace the grating by an acousto-optic tunable filter (AOTF). This device is composed of an optical medium in which the light is diffracted by an acoustic wave. Its major advantage is that it is a completely passive device: no mechanisms, no cut order glass and no slit like in grating monochromator system are required.

This instrument is selected for the mission ESA/ExoMars rover mission [7] in the reduced spectral range 0.9-2.6 µm due to thermal, mechanical and power constraints. To demonstrate the feasibility of MicrOmega, we have developped at IAS a full breadboard of the instrument in the ExoMars configuration. It is designed to characterise

MicrOmega and shows its performances. We describe the breadboard and show the results.

2. The breadboard of the ExoMars instrument

We realized at IAS a full breadboard of the MicrOmega IR instrument (fig. 1). This breadboard is composed of the instrument demonstrator (highlighted by the red ellipse) and of the ground system equiment that simulates the rover interface and environnement. The instrument is coupled to a radiator which simulates the Rover cold Finger. This radiator is essential to dissipate the output power generated by a thermoelectric cooler (TEC). This TEC cools down the detector to 190 K in order to have a low dark current. The temperature of this radiator is controlled not to exeed 263 K on the hot plate of the TEC. The whole breadboard is purged under a nitrogen atmosphere and humidity controlled chamber in order to avoid condensation on the breadboard while the radiator temperature is below 273 K.

The detector is a Sofradir Mars SW 320 x 256 pixels, HgCdTe matrix. This detector has a sensibility from 0.9 to 2.6 µm with a cut off wavelength of 2.53. The monochromatic light is generated by an AOTF with its own illumination system (fig. 2). The optics used in the demonstrator are the spare optics from the Rosetta/CIVA MI model. It is a two doublet lens system with a magnification of one.

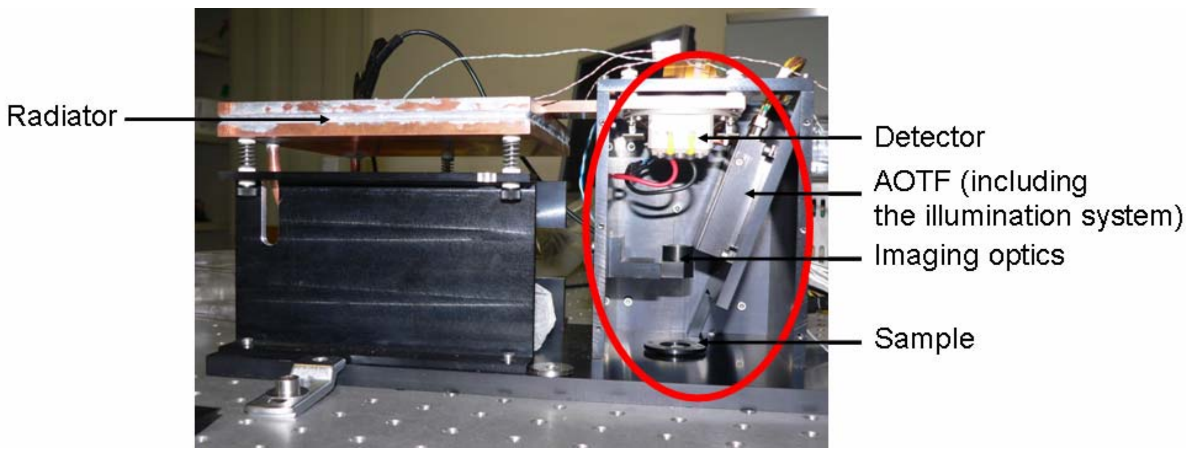

Fig. 1: MicrOmega Breadboard. The demonstrator of the instrument is shown in the red ellipse. The size of this box is 120 mm height and 80 mm width.

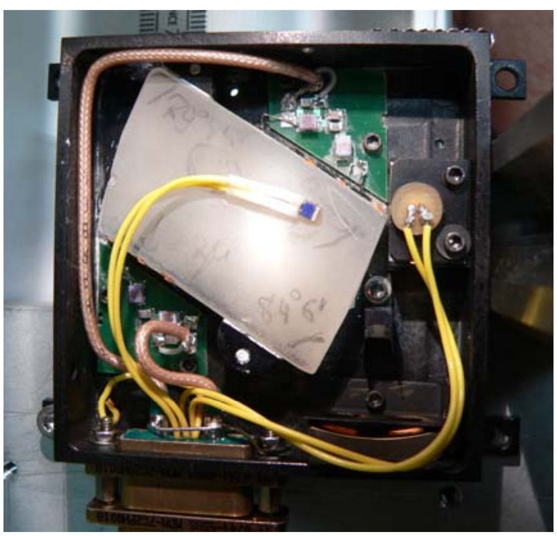

Fig. 2: The AOTF and its illumination system used in the breadboard.

The optical diagram of the demonstrator is shown in fig. 3. The AOTF illuminates the sample with an incidence angle of 20°. The optical axis of the imaging optics is perpendicular to the surface of the sample. It images the sample directly on the detector.

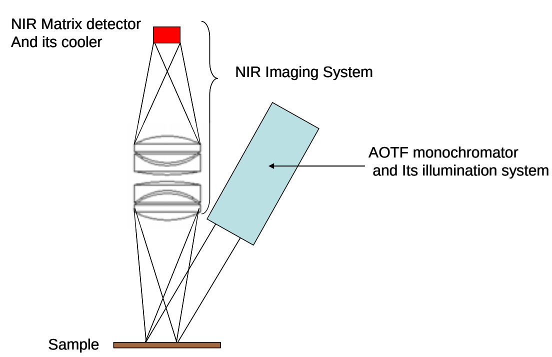

Fig. 3: Optical diagram of the demonstrator of the MicrOmega Instrument. The AOTF output beam makes an angle of 20° with the optical axis of the NIR imaging system

3. Experiment Protocol

The aim of the instrument is to measure the reflectance spectra of the samples. To measure them, we proceed as shown in fig. 4. First we acquire an image with the AOTF OFF to get the reflective background. Then we acquire an "image cube" of the sample with the AOTF ON. Finally we repeat the measurement with a reference target; in our case we choose the Lambertian labsphere SPECTRALON, coupled to a great reflectivity up to 98% [8].

We process the data as follows: first we substract the background to the sample and reference "image cube". Then we divide the one by the other, pixel per pixel, and we obtain an "image cube", each pixel containing a spectrum of the areas viewed.

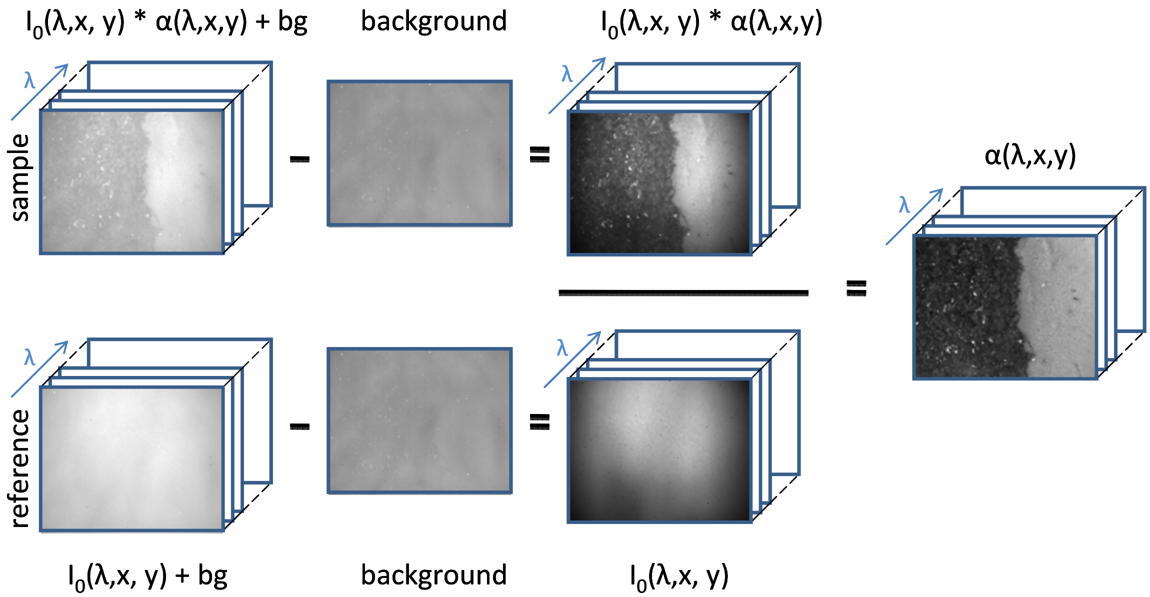

Fig. 4: Protocol used to acquire and measure the reflectance of a sample.

4. Results

Up to now, we have tested two types of samples: powders and rocks. We selected three types of minerals: clays (nontronite) with narrow and intense absorption bands, sulfates (kieserite) and mafic minerals (pyroxene or olivine) with large bands and characteristic slopes.

The powder was composed of either one component, or two components, or a mixture of both components (an example is shown in fig. 5). This sample was analysed by MicrOmega and the results are shown in fig. 6.

Fig. 5: Image of a sample analysed with MicrOmega. It is composed of three different areas, two made with a pure component (a sulfate and a clay) and a mix of both components

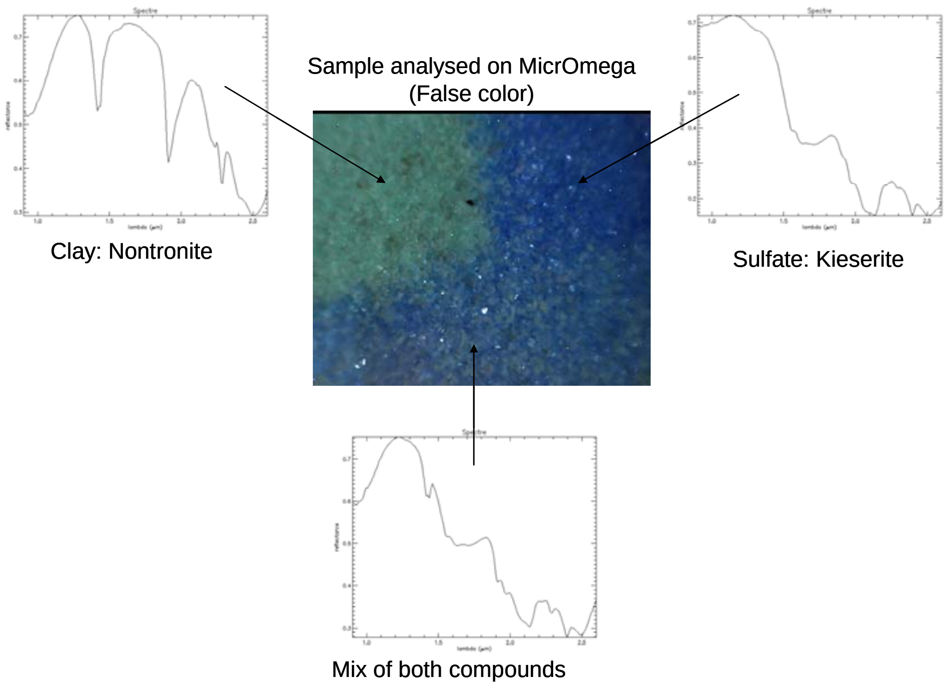

Fig. 6: The same sample as in fig. 5 analysed by the MicrOmega instrument. The image in the center is in false colors. For each area, a spectrum is shown.

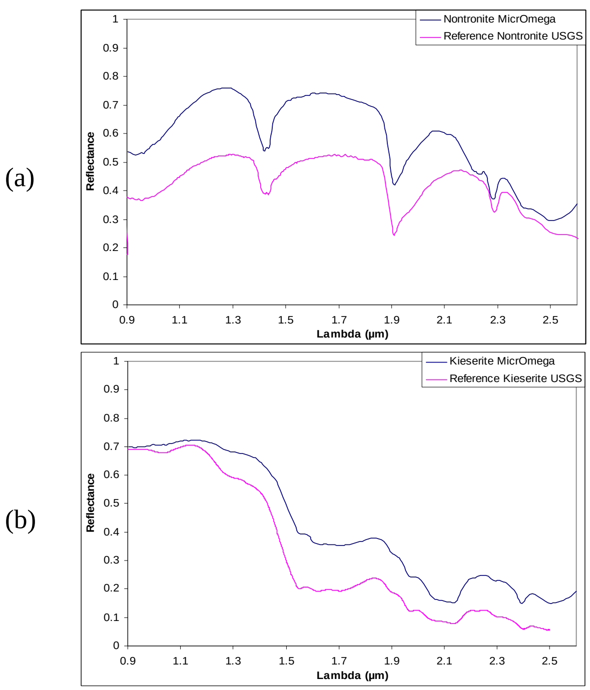

Fig. 7: Comparison of the spectrum above with the USGS database for each pure minerals (a) nontronite, (b) kieserite.

We also test our instrument on a Martian analog. The results show that we have the capability to analyse and identify each mineral in the sample, at the grain size. The fig. 8 and the fig. 9 represent each a map in false colors showing the two different families of minerals presents in our sample: the low calcium pyroxene, and the high calcium pyroxene. This map was obtained using the spectral parameter used for Omega data processing. We calculate the ratio of two bands in the spectrum in order to emphasize one type of minerals. For the High calcium pyroxene, we take the ratio of the 1.6 – 1.7 µm band to the 2.2 - 2.3 µm band and for the low calcium pyroxene, the ratio of the 1.25 – 1.35 µm band to the 1.8 – 1.9 µm band. The two maps show the instrument’s capability to identify the grains of each family.

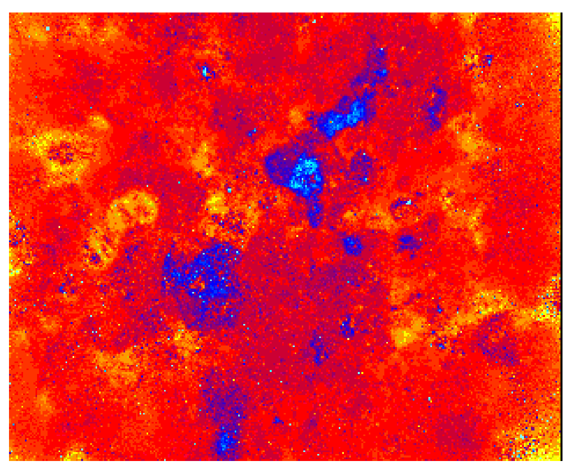

Fig. 8: Map in false colors that exhibits the high calcium pyroxene (in blue).

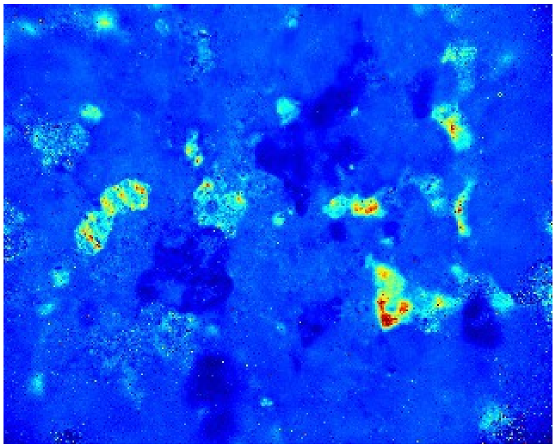

Fig. 9: The same sample but with a processing that shows the Low calcium pyroxene (in red and green).

5. Extension of the spectral range up to 4 µm

MicrOmega is designed to cover the extended spectral range 0.9 – 4 µm. In this configuration, the whole instrument needs to be cooled down to 150 K in order to reduce the thermal contribution. The problem is that we need to qualify and design the AOTF and all the components of the instrument (detector and optics) to survive such low temperatures. The detector and the optics are not a problem because solutions exist. Nevertheless, up to now, nobody succeed in qualifying an AOTF down to this temperature. A research and technology program, supported by CNES has been launched since several years. The problem was to weld all the materials of the AOTF (transducers, crystal and box) and to still work at 150 K. A solution was found and we tested the technology down to 140 K (fig. 10).

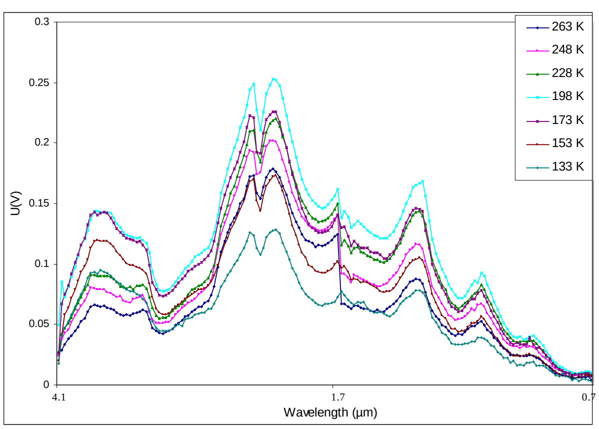

Fig. 10: Thermal test done on a demonstrator AOTF. It shows that we have now a technology that works at low temperature (down to 140 K).

6. Perspective

Our tests and results show that the MicrOmega IR has reached its goals: capacity to identify minerals, low power consumption, good signal to noise ratio. Even if all the subsystems used, for example the imaging optics, are not optimized for the instrument, we have demonstrated the feasibility of the instrument.

The next step will be to realise the qualification model of MicrOmega to go through thermal and vibrations tests. The AOTF has already been tested at low temperature and some tests will be done soon in order to qualify it in vibrations. With this qualification model, we will have also to test its full performances and its limits.

REFERENCE

1. Bibring J.-P., et al., OMEGA: Observatoire pour la minéralogie, l'eau, les glaces et l'activité, in Mars Express: The Scientific Payload. Edited by A. Wilson, pp. 37 - 50, Eur. Space Agency, Noordwijk, Netherlands, 2004.
2. Squyres S.W., et al., Two Years at Meridiani Planum: Result from the opportunity Rover. Science, Volume 313, Issue 5792, pp. 1403-14073, 2006.
3. Bibring J.-P., et al., Global Mineralogical and Aqueous Mars History Derived from OMEGA/Mars Express Data. Science 312, 400 – 404, 2006.
4. Poulet F., et al.,. Phyllosilicates on Mars and implications for early martian climate. Nature 438, 623 – 627, 2005.
5. Berthe M. and J.P. Bibring, AGU Fall Meeting 2006, Abs. #P53A-05, 2006.
6. Leroi V., et al., MicrOmega: Design and Status of a near-infrared spectral Microscope for in situ analysis of Mars Samples, Planetary and Space Science (under submission).
7. Vago J., et al., ExoMars - searching for life on the Red Planet. ESA Bulletin (ISSN 0376-4265), No. 126, p. 16 – 23, 2006.
8. Bruegge C. J., Stiegman A. E., and Rainen R. A., Use of Spectralon as a diffuse reflectance standart for in-flight calibration of earth-orbiting sensors., Optical Engineering, vol.32 n°4,805-814, april 1993.