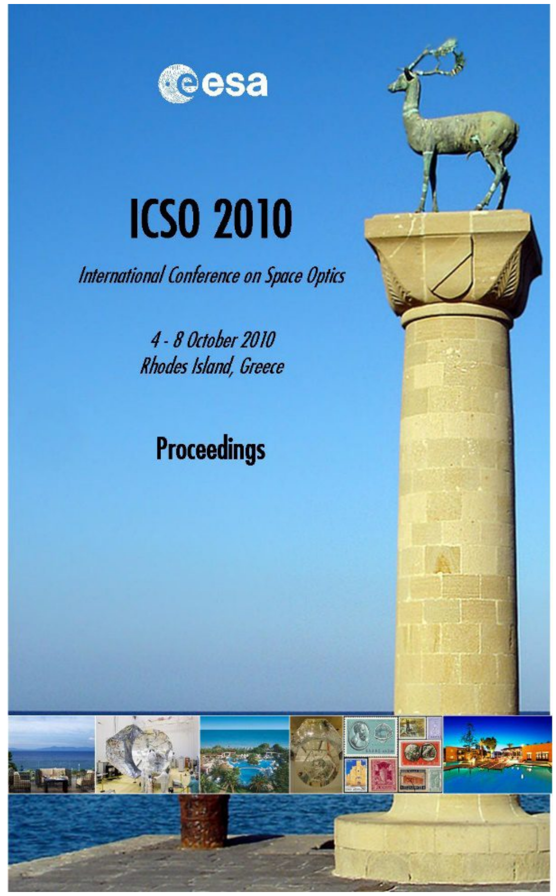
International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

Edited by Errico Armandillo, Bruno Cugny, and Nikos Karafolas



Micromega IR, an infrared hyperspectral microscope for space exploration

C. Pilorget, J.-P. Bibring, M. Berthe, V. Hamm

International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny, Nikos Karafolas, Proc. of SPIE Vol. 10565, 1056515 · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309147

MICROMEGA IR, AN INFRARED HYPERSPECTRAL MICROSCOPE FOR SPACE EXPLORATION

C. Pilorget[1], J.-P. Bibring[1], M. Berthe[1], V. Hamm[1].
[1]*Institut d'Astrophysique Spatiale, Université de Paris Sud, 91405 Orsay, France.*

I. INTRODUCTION

The coupling between imaging and spectrometry has proved to be one of the most promising way to study remotely planetary objects [1][2]. The next step is to use this concept for *in situ* analyses. MicrOmega IR has been developed within this scope. It is an ultra miniaturized near-infrared hyperspectral microscope dedicated to *in situ* analyses, selected to be part of the ESA/ExoMars rover and RKA/Phobos Grunt lander payload. The goal of this instrument is to characterize the composition of samples at almost their grain size scale, in a nondestructive way. Coupled to the mapping information, it provides unique clues to trace back the history of the parent body (planet, satellite or small body) [3][4].

II. INSTRUMENT CONCEPT

MicrOmega acquires in situ reflectance spectra of 5 mm-sized samples with a spatial sampling of 20 µm. A monochromator, based on an AOTF (Acousto Optical Tuneable Filter), illuminates sequentially the sample in up to 500 contiguous wavelength channels covering the spectral range of interest (0.9 - 3.5 µm). For each channel, an image is acquired on a 2D detector, building a tridimensional (x,y,λ) image cube. The baseline choice for MicrOmega of its spectral domain, from 0.9 µm to 3.5 µm, as well as that of the spectral sampling, of ~ 20 cm^{-1}, is derived from the experience gained with laboratory and space analyses [5]. In this 0.9 to 3.5 µm spectral domain, most molecules, radicals and boundings have specific quantified energy modes (EM transitions, charge transfers or vibration), so that most minerals, ices, and even some organics, have spectral signatures with diagnostic properties: band shape and central position. As opposed to gaseous species, solid compounds exhibit larger spectral features, so that a moderate spectral sampling is sufficient to identify them.

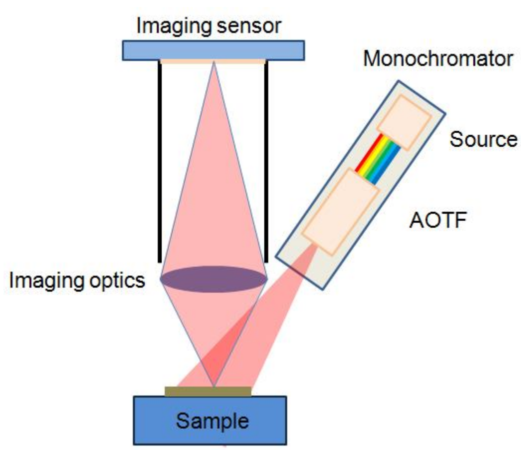


Fig. 1. MicrOmega concept diagram with its subsystems: monochromator, imaging optics and imaging sensor.

III. MEASUREMENT PROTOCOL

The goal of the instrument is to get a reflectance spectrum for each pixel of the matrix. However, the instrument response depends of the wavelength. We thus need to calibrate it by a reference "white" target. Furthermore, the signal measured by the detector does not contain exclusively the monochromatic light diffused by the sample. It also contains three other components: the dark current of the detector, the thermal flux coming from the environment seen by the detector and the straylight coming from the monochromator. In order to retrieve the monochromatic diffuse part, we acquire the background (dark current + straylight + thermal flux), subtract it from the total measured signal (protocol described in Fig. 2) and then divide it by that acquired with the reference target.

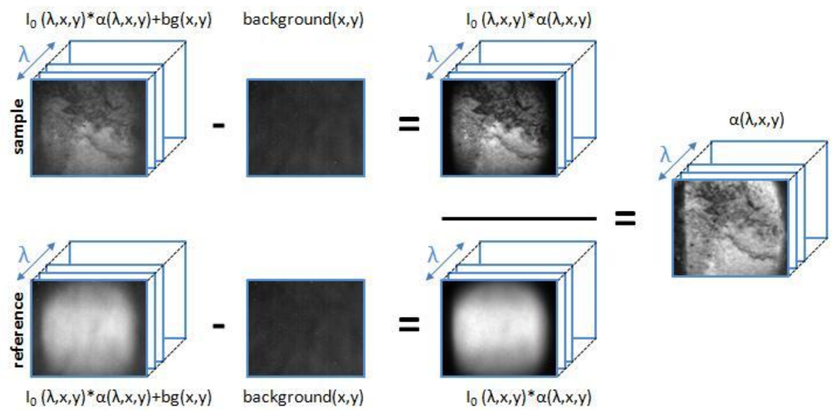


Fig. 2. MicrOmega protocol to get reflectance spectra

IV. AN AOTF MONOCHROMATOR AS ILLUMINATION DEVICE

A. AOTF concept

One of the most critical devices in the instrument is the monochromator. We have chosen not to use a standard rotating grating. Instead, we use an AOTF illuminated through a beam condenser by a white source from a tungsten filament lamp. The light is partly diffracted inside the AOTF and a monochromatic light exits the crystal in a given direction, distinct from that of the non diffracted (white) light. The functioning of this component is based on the anisotropic Bragg diffraction [6]. When an acoustic signal (produced by a RF generator in our case) is applied on the crystal, it produces a strain that changes its optical properties: as it propagates, it creates regions of compression and rarefaction. This acoustic field within the crystal creates a periodic refractive index modulation that can be seen as a grating with which the optical beam interacts. The grating step size is given by the acoustic signal wavelength. At a given acoustic frequency corresponds a given and unique diffracted wavelength. Tuning the frequency of the acoustic wave with an RF generator is therefore used to select the wavelength of the diffracted beam. In our case, the light is injected in a birefringent crystal. Some of this light is diffracted and undergoes a rotation of its polarization by 90°. At the end, two beams exit the crystal: the 0^{th} order (non-diffracted beam) and the 1^{st} order (diffracted beam). Different aspects have been tested to evaluate the efficiency of the AOTF as a monochromator: 0^{th} to 1^{st} order energy conversion, full-width half-maximum (FWHM), out of band transmission and 0^{th} order rejection.

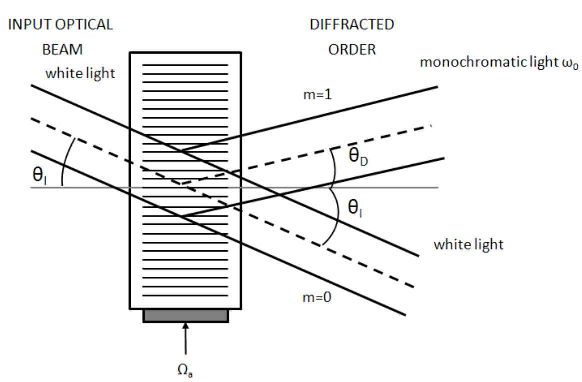


Fig. 3. AOTF concept. When a sine ultrasonic acoustic wave is applied to the crystal, a monochromatic light (1^{st} order) exits the crystal in a given direction, distinct from that of the non diffracted white light (0^{th} order).

B. Perfomances

Tests were performed by injecting a monochromatic light beam in the AOTF and by varying the frequency of the acoustic wave. We used a 1310 nm laser diode coupled with an aperture stop, a linear polarizer and a Germanium detector. An input power of 1.58 W was used for the RF generator (all the tests were performed with a constant RF input power).

- 0^{th} to 1^{st} order energy conversion:

Fig. 4 shows the spectral evolution of the amplitude of the 0th and 1st orders. Variations of the 0th order amplitude correspond to the opposite variations of the 1st order, which is consistent with the energy conservation theory. With an RF input power of 1.58W, a maximum of 74% of energy conversion is reached at about 7634 cm^{-1}, which corresponds to 1310 nm. Typical conversion rate of 95% can be reached when increasing the RF input power.

- full-width half-maximum and out of band transmission:
  One of the main concerns when designing a monochromator is to get the smallest full-width half-maximum with the highest SNR. However, this is definitely not sufficient to characterize the efficiency of this device. The energy of the background should also be negligible compared to the energy of the main peak. Indeed, when illuminating a sample at a given wavelength, it is not acceptable that a non-negligible part of the measured signal is due to the response of the sample at other wavelengths. A full-width half-maximum of 20 cm^{-1} was measured with a Gooch and Housego AOTF. As can be seen on Fig. 4, the signal level decreases quickly when the scan frequency is far from the main peak: it is less than 0.1% of the main peak level about 200 cm^{-1} away from the main peak.

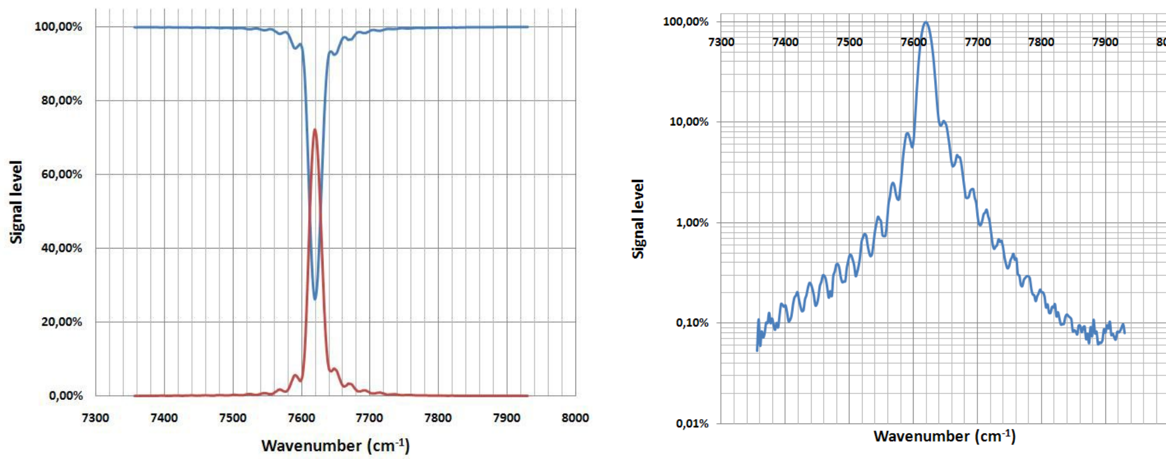


Fig. 4. On the left: 0th order in blue and 1st order in red. About 74% of the 0th order is converted to the 1st order at the center frequency with a RF power of 1.58 W. On the right: 1st order signal level (log scale).

- Straylight rejection:
  Since the angular separation between the 0th and 1st orders beams is only a few degrees, a combination of linear crossed polarizers and light trap is used to decrease the level of the non-diffracted light to a level in the order of the percent.

We also acquired a spectrum of a reference sample (Labsphere calibration standard) with both a FTIR PerkinElmer spectrometer and a fully representative breadboard of the MicrOmega instrument, developed at Institut d'Astrophysique Spatiale [7], and using a Gooch and Housego AOTF. Fig. 5 shows that the spectrum is very well reproduced and that the resolution of the instrument is sufficient to detect small typical spectral features.

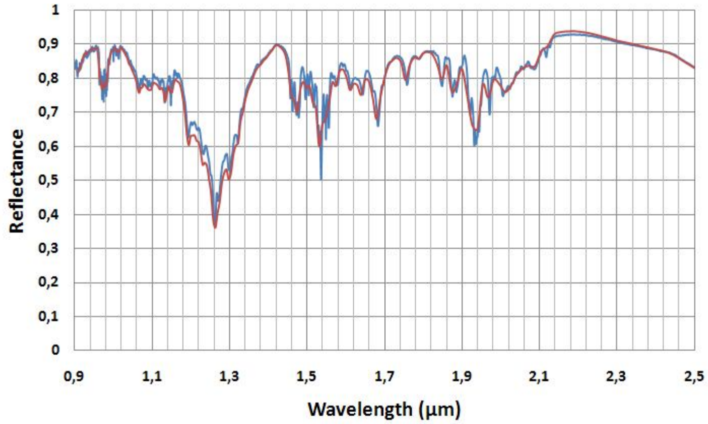


Fig. 5. In blue: Labsphere calibration standard spectrum acquired with a FTIR PerkinElmer spectrometer ; in

red: spectrum acquired with a representative breadboard of the MicrOmega instrument (each measure was acquired every 5 cm^{-1} with the FTIR spectrometer and every 37 cm^{-1} with the representative breadboard).

These results show the capability of an AOTF to be used a monochromator for our instrument. They can generate very narrow-band signals that can be considered as monochromatic, with a very good out of band rejection. Furthermore, AOTFs are compact devices, using only an electric signal to tune the wavelength of the output beam. The full instrument thus requires no moving part, which increases critically the robustness of space devices.

V. MICROMEGA PHOBOS GRUNT

A specific version of MicrOmega is currently developed at IAS to be implemented on board the Phobos Grunt lander (launch in 2011). This instrument will have to analyse samples from this martian moon and should provide essential clues as to the origin of Phobos. Its spectral range (0.9-3.2 µm) is chosen to identify mafic minerals, ferric oxides and hydrated phases. It should also be sufficient to detect some organic compounds. The samples will be collected and delivered to the instrument by a robotic arm.

A Sofradir MCT detector with a spectral range from 0.9 to 3.2 µm has been chosen. Since the spectral range goes up to 3.2 µm, the detector needs to be cooled down to about 110 K in order to limit the dark current. This temperature cannot be reached by using peltier thermoelectric coolers, but only by a cryo-cooler. A Ricor K508 microcooler has been chosen for MicrOmega Phobos Grunt. It is currently tested at IAS. Another aspect related to the upper limit of the spectral range is the sensitivity to the thermal flux. Each part of the instrument has a gray body behavior and therefore emits thermal infrared photons. As the detector goes further in the infrared, it receives more of these photons. Since all parts seen by the detector cannot be cooled down, the field of view of the detector must be reduced. A cold baffle, cooled by the cryo-cooler, is present within the detector module and an aperture stop, cooled down to 250 K, has been added between the detector and the imaging optics (composed of a telecentric objective). This way, thermal flux is limited to an acceptable level.

VI. MARS AND BEYOND

After Phobos Grunt, MicrOmega will fly on the ESA ExoMars mission. Its spectral range will be extended to 3.5 µm in order to better detect and identify the possible organic compounds. Furthermore, the MicrOmega mapping capabilities will play a key role in the investigation process on a sample. Samples will be first analyzed by MicrOmega. The analyses results will be processed onboard the rover to identify the relevant areas where other instruments (like the RAMAN spectrometer for instance), which have much smaller spots, will have to work. Algorithms are currently developed at IAS to perform this task.

REFERENCES

[1] Bibring J.-P., et al., “Global Mineralogical and Aqueous Mars History Derived from OMEGA/Mars Express Data”. *Science*, 312, 400 – 404, 2006.
[2] Poulet F., et al.,. “Phyllosilicates on Mars and implications for early martian climate”. *Nature*, 438, 623 – 627, 2005.
[3] Leroi V., Bibring J.-P. and Berthe M., “MicrOmega: a VIS/NIR hyperspectral microscope for in situ analysis in space”. *Planetary and Space Science,* Volume 57, Issues 8-9, July 2009, Pages 1068-1075.
[4] Berthe M. and Bibring J.-P., “MicrOmega: a NIR hyperspectral microscope for in situ compositional analyses”. *AGU Fall Meeting*, 2006.
[5] 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.
[6] Goutzoulis A.P. and Pape D.R., *Design and fabrication of acousto-optic devices*. Edited by Dekker Inc., 1994.
[7] Leroi V., Bibring J.-P., Berthe M., “MicrOmega IR: a new infrared hyperspectral imaging microscope for in situ analysis”. *ICSO proceedings*, 2008.