THE MACROMEGA INSTRUMENT ON-BOARD MMX, AN ULTRA-COMPACT NIR HYPERSPECTRAL IMAGER BASED ON AOTF TECHNOLOGY: PRELIMINARY TESTS ON A BREADBOARD

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Introduction: The origin of the Mars moons Phobos and Deimos, critical to constrain the early dynamics of the solar system, is still highly controversial. Their spectral properties and asteroid-like shape suggest a small body capture [1, 2, 3], but their orbital properties (e.g. their very circular equatorial orbit) point towards an in situ formation subsequent to a giant impact on Mars [4, 5, 6]. The MMX (Martian Moons eXploration) ISAS/JAXA mission [7], to be launched in 2024, is primarily designed to assess Phobos and Deimos origin, by characterizing their global composition, remotely, in situ, and through analyses of samples returned to Earth. In orbit around Mars during almost two Martian years, MMX will also have the capability to perform a long-term monitoring of Mars atmosphere.

The MacrOmega instrument, developed in the frame of a partnership between France and Japan, will play a central role in this investigation.

MacrOmega within MMX: MacrOmega is a hyperspectral imager body mounted on the MMX spacecraft, operating in the near infrared (from 0.9 to 3.6 µm). The instrument will perform observations of Mars, Phobos and Deimos at various scales during different observation phases. Their combination will contribute to obtain a multiscale dataset of Phobos (global mapping at 12 m resolution, down to 0.4 mm at landing), Deimos (global mapping at ~50 m resolution) and Mars (2.5 and 25 km resolution from regional to global scale). This coupling, between high resolution imagery and spectroscopy will provide unprecedented data to constrain the formation and evolution of the Martian moons; it will also contribute to the remote selection of the sample collection site at Phobos. Once landed, MacrOmega observations will help the collection process in characterizing the level of potential compositional heterogeneity down the mm scale. Mars atmosphere observations will focus on high temporal resolution monitoring of H_2O/CO_2 clouds, water vapor and aerosols, as well as other minor compounds.

The MacrOmega concept: MacrOmega is a NIR hyperspectral imager based on a novel concept inherited from the technological breakthrough from MicrOmega/ExoMars [8] and MicrOmega/Hayabusa2 [9]. Like MicrOmega, MacrOmega key point is the use of an Acousto-Optic Tunable Filter (AOTF) as dispersive system which provides a diffraction efficiency higher than a classical grating and without any moving parts. But contrary to MicrOmega where the AOTF is used to illuminate the scene with a monochromatic beam, later scattered by a sample and imaged on a 2D detector [10, 11], in the MacrOmega configuration, the AOTF is used in the imaging light beam : the monochromator filters the sunlight diffused by a remote scene, to make monochromatic image on the detector. By tuning the AOTF frequency, a 3D image cube (x,y,λ) is sequentially built. The way to operate MacrOmega is therefore fully different from former imaging spectrometers like OMEGA/Mex and CRISM/MRO.

The AOTF contains a TeO_2 crystal which, when excited by acoustic waves *via* RF piezoelectric transducers, diffracts light selecting one wavelength, according to the Bragg's diffraction law. The properties of the diffracted beam depends on the crystal geometry which constrains the acoustic field geometry. Basically, the length of the acoustic interaction determines the spectral width of the beam, the filtering efficiency depends on the injected RF power and the shape of the transducers gives the shape of the spectral filtering function (sinc²-like for rectangular transducers). The AOTF has a 20 cm^{-1} FWHM, *i.e.* 1.6 to 26 nm on the instrument spectral range, which enables to identify most of the minerals (silicates, hydrated minerals, oxides, salts), ices (e.g. H_2O, CO_2) and organics. Its large aperture will contribute to increase the SNR which is critical when observing low albedo surfaces and it will also improve the image quality by pushing the diffraction limit.

Preliminary performances tests: To validate MacrOmega's concept, to explore any potential limitations and characterize its future performances, a breadboard of the instrument has been developed at IAS. For this purpose, we use a 128x128 px² HgCdTe detector imaging various scenes through a 15x15 mm² aperture AOTF. These tests are currently performed in ambient conditions.

Several preliminary tests have been performed to characterize both the imaging and the spectral performances. The later are linked to the monochromator quality of the AOTF and the photometry performances of the instrument (SNR and image quality). The crystal has to provide a spectrally narrow beam (defined as the FWHM of the central lobe), low side lobes and high filtering efficiency. As can be seen on Fig.1, preliminary tests show good performances, with a narrow central lobe (~ 20 cm^{-1}), compliant with MacrOmega specifications and a good rejection of the secondary lobes. However, optimizations are presently under study, to enhance them.

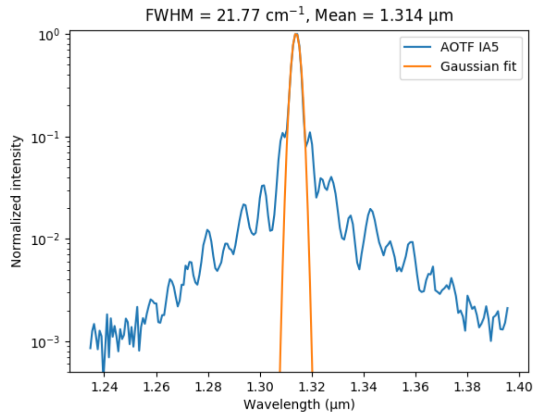

Figure 1: *Filtering function of the AOTF probed by a 1.31 µm laser diode and Gaussian fit calculated over the main diffraction lobe. We measured a spectral width of 21.77 cm^{-1} which corresponds to 3.76 nm @ 1.314 µm. Note that the observable modulations are due to diffraction side lobes, the noise floor level being about 10^{-3}.*

MacrOmega results have also been compared to a Fourier transform IR spectrometer (Perkin-Elmer lab FTIR spectrometer) by acquiring reference sample spectra: polymethyl methacrylate and polyethylene (see *Figure 2*), which exhibit several diagnostic NIR spectral features, with various shape, depth and width. These tests show a very good consistency between both instruments results, even for the smallest spectral features.

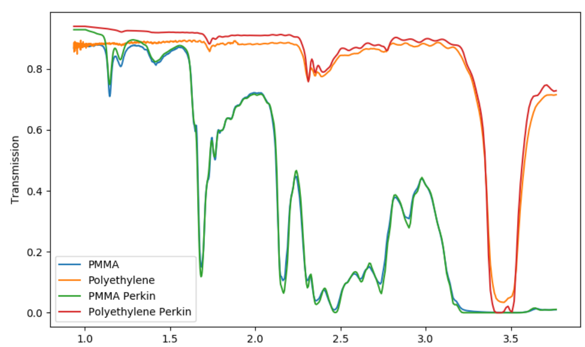

Figure 2: *Polymethyl methacrylate (PMMA) and polyethylene spectra acquired with the MacrOmega breadboard (blue/orange) and the PerkinElmer FTIR spectrometer (green/red). Spectra obtained with the FTIR spectrometer have been convolved with a 20 cm^{-1} width gaussian and set to a similar spectral sampling as MacrOmega spectra. The small modulations observable at 1.7 and from 2.5 to 3 µm are not sample spectral features but interferences caused by the parallel faces and the thinness of the sample (polyethylene foil).*

Imagery performances have also been checked by taking pictures of a sharp edged image and of a blackbody with increasing temperature. These tests are promising since no particular blur or artefact are visible on the image. Further tests are scheduled to characterize more deeply the instrument performances, such as the wave front analysis, the determination of the point spread function, the acoustic field uniformity and the impact of the side lobes on the image quality.

References:

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