CALIBRATION OF MICROMEGA HAYABUSA-2 FLIGHT MODEL – FIRST RESULTS. L. Riu[1], J-P. Bibring[1], V. Hamm[1], C. Pilorget[1], F. Poulet[1], [1]Institut d'Astrophysique Spatiale,Université Paris-Sud, 91405 Orsay cedex, France. Contact: lucie.riu@ias.u-psud.fr

Introduction: The JAXA (Japanese Aerospace Exploration Agency) Hayabusa-2 mission was launched in December 2014 towards, RYUGU, the C-type Asteroid 1999JU3 [1]. It carries MASCOT (Mobile Asteroid Surface sCOuT), a 10 kg lander witha suite of four instruments including the hyperspectral microscope MicrOmega (MMEGA) that was developed at the Institut d'Astrophysique Spatiale (IAS/Orsay) [2].

MMEGA operates between 1 µm to 3.55 µm with a spectral resolution of ~ 20 cm^{-1} providing a spectral sampling of 5 to 15 nm at 1 to 3.55µm respectively. The dispersive system is based on an AOTF (Acousto-Optic Tunable Filter). For each wavelength, the sample is illuminated with a monochromatic light, and the image is acquired on a 2D detector providing a FOV of 3.2×3.2 mm² with a spatial sampling of 25 µm. The complete 3D spectral cube is built by sequentially scanning the illuminating wavelength over the full spectral range. In this spectral range, most constituents of relevance (minerals and organics) have diagnostic signatures: their identification enables to study the petrology and the alteration history of the asteroid surface and to potentially detect and characterize carbon-rich phases.

Interpretaing the data that shall be acquired in terms of actual physical properties requires an in-depth calibration to be performed: it was conducted, at IAS premises prior to launch. We here below present the method used to acquire reflectance spectra for each pixel within the FOV, and discuss some of the results obtained.. This includes: 1) the evaluation and the modeling of the different thermal contributions; 2) the radiometric calibration, consisting of derivation of a specific 4-D transfer function depending on the pixel position, the AOTF temperature and the selected frequency; 3) the spectral calibration. We below describe these different calibration activities.

Dataset: MMEGA calibration data were acquired in a vaccum chamber under various controlled temperature conditions. Three different targets were used: *Spectralon 99%* (which can be considered as lambertian), *Wavelength Calibration Standard* (which presents several absorption bands in the NIR), *Infragold* (which is spectrally flat in the NIR) from Labsphere. In additiuon, terrestrial mineral samples have been also imaged.

Thermal contribution: A quantitative analysis of the thermal contribution is mandatory to evaluate operational parameters (e.g. integration time) and to estimate the expected signal to noise ratio. Specifically, the detector receives thermal emission coming from the detector environment (instrument cavity and sample) in addition to the monochromatic signal coming from the sample. Assuming the thermal contribution is spectrally similar to a black body emission, it can be modelled as follow (measured in ADU) :

$$S(T) = \sum_{N} \int_{\lambda_{min}}^{\lambda_{max}} G \times C \times L_{\lambda} \times \varepsilon \times T_r \times QE(\lambda) \times \frac{\lambda}{hc} d\lambda$$

where λ_{min}=0.9µm, λ_{max}=3.9µm, G is a geometric constant depending on the pixel surface, the solid angle Ω from which the environment is seen by the detector, C the gain used to convert ADU in number of photons, L_{λ} is the Planck function, ε the emissivity of the environment, T_r the optical transmission, QE the quantum efficiency of the detector, N number of contributions. Here N is equal to 2 corresponding to two distinct contributions: one from the sample (ε_{sample}, T_{sample}, Ω_{sample}) and one from the instrument ($\varepsilon_{instrument}$, $T_{instrument}$, $\Omega_{instrument}$).

As a result, the thermal contribution can be assessed and compared to the overall signal at any temperature and for any sample with known emissivity.

Radiometric calibration: The wavelength at which the sample is illuminated is selected thanks to the RFS (Radio Frequency Synthesizer) frequency applied to the AOTF crystal. For each pixel, the radiometric response depends on the AOTF frequency and the temperature of operation. The pixel to pixel response (flat fielding) must thus be characterized with these two sets of parameters.

Two samples with adequate spatial and spectral responses were combined to build the 4D-transfert function : an *Infragold* sample, which is spectrally flat on the MicrOmega wavelength range and a *Spectralon 99%* ("White Spectralon") that is spatially homogenous (Figure 1).

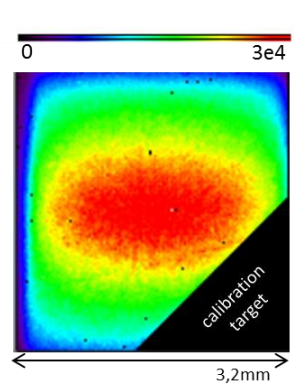

Figure 1. *Top: Raw signal of White Spectralon – at 1.7µm in ADU/s.*

By combining those two responses, we are able to build a radiometric standard response with the characteritics of both samples. The radiometric response is computed with the *Infragold* sample and the spatial variation of this response is obtained thanks to the *Spectralon 99%*. This function is interpolated for any AOTF temperature between -40°C to +40°C, which covers the instrument operating range once MASCOT will have landed on the asteroid.

This 4D-transfer function will thus allow the computing of reflectance image cubes, according to the AOTF frequency, from digitized data measured by MMEGA at any temperature, and for every pixels.

Spectral calibration: The conversion of RFS frequency to wavelength, which depends on the AOTF temperature, has also to be calibrated. In order to perform this spectral calibration, we used a *Wavelength Calibration Standard* that exhibits several absorption features between 1 and 2.5 µm (Figure 2).

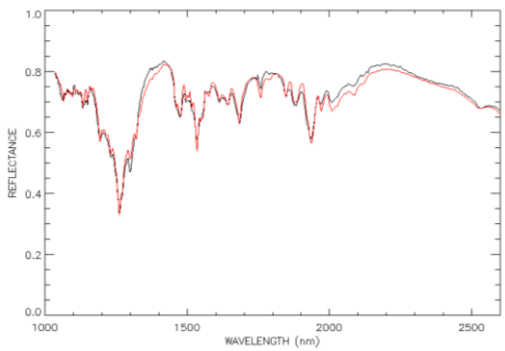

Figure 2. *Wavelength Calibration Standard reflectance spectrum obtained when dividing the raw signal with the radiometric standard response at the corresponding temperature (-40°C) (black) compared to a reference spectrum presenting same spectral resolution and spectral sampling (red).*

The spectra were acquired for different AOTF temperatures, from -40°C to +40°C and compared to a reference *Wavelength Calibration Standard* spectrum (Figure 2) acquired with a PerkinElmer FTIR spectrometer that provides comparable spectra. The position of the bands observed on the MMEGA spectrum can then be compared to the position of the same bands in the reference spectrum. The relation between the AOTF frequency, the wavelength and the temperature was modelled as follow:

$$\lambda(F,T) = A(T) + \frac{B(T)}{F + C(T)}$$

where A, B and C coefficients were determined in order to minimize the Residual Mean Square value between the reference spectrum and the MMEGA spectrum. This optimization was made for all available temperatures and interpolated on the entire -40°C to +40°C range. The spectral calibration enables the building of reflectance image cubes according to the wavelength which allows the determination of absorption features locations.

Mineral sample validation: As an illustration of the calibration, representative samples observed with MMEGA are presented in Figure 3. All the spectral characteristics of these targets are retrieved. This demonstrates that the 4-D radiometric transfer function combined with the spectral calibration enables the conversion of the digitized data measured by MMEGA in reflectance image cube that shall allow the characterization at microscopic scale of the observed minerals, and the study of physical properties of the asteroid surface.

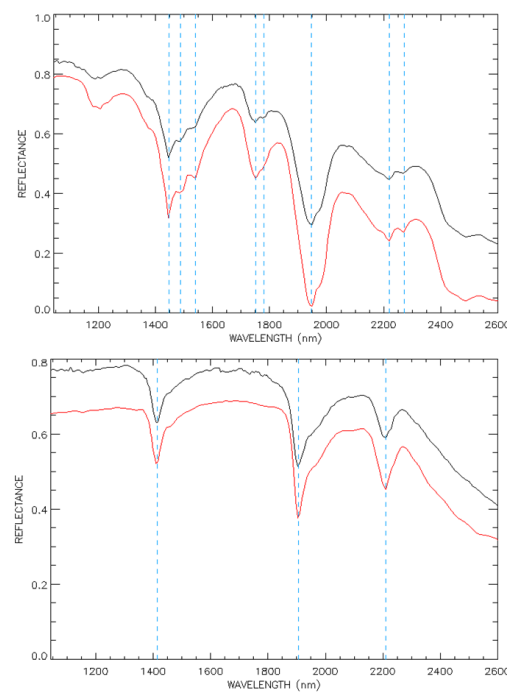

Figure 3. *Top: Gypsum reflectance spectrum measured with MMEGA (black) compared to reference gypsum reflectance spectrum (red). Bottom: Montmorillonite reflectance spectrum measured with MMEGA (black) compared to reference montmorillonite reflectance spectrum (red) - Temperature (~25°C), average on the FOV, offset for clarity.*

References: [1] Tsuda Y., et al. (2013), *Acta Astronautica*, volume 91, 356-362. [2] C. Pilorget and J.-P. Bibring, (2013), *Planetary and Space Science*, volume 76, 42-52.