MMX INFRARED SPECTROMETER PERFORMANCES ASSESSED BY SIMULATIONS. N. Théret[1], L. Jorda[2], E. Sawyer[1], A. Barrucci[3], J.-M. Reess[3], P. Bernardi[3], M. Castelnau[1], A. Rouvié[1], M. Le Du[1], V. Piou[1] [1]CNES, 18 av. E. Belin, Toulouse, France (nicolas.theret@cnes.fr), [2]LAM, 38 rue F. Joliot Curie, Marseille, France, [3]LESIA, 5 place J. Janssen, Meudon, France.

Introduction: The Martian Moons eXploration (MMX) mission is led by JAXA and aims at determining the origin of Phobos and Deimos in the Martian system[1]. One of its instruments is an imaging spectrometer called MIRS (MMX InfraRed Spectrometer), operating in the range of 0.9µm-3.6µm[2]. This paper describes MIRS simulations.

MIRS Simulations Objectives: In order to help developing the data processing ground segment, to anticipate the operations (especially the landing site selection), to prepare the science use of the data and to assess the reachable performances, it has been decided to lead system simulations, including mission programing[3] and image acquisition. These simulations involve three chained simulators (Fig. 1): AURORA[4] constructs mission scenarios, OASIS[5] generates ground truth as observed from MMX probe, and MIRAGES simulates the instrument response to produce MIRS images. The mission programming part has already been presented in [3], thus this paper focuses on image simulations.

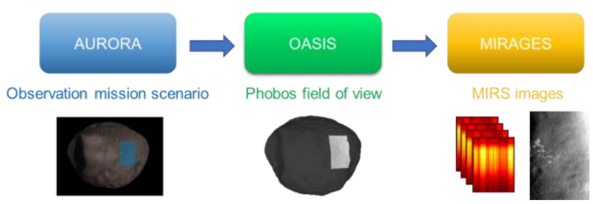

Figure 1. *The System Simulation chain*

Rendering of the Scenes: The rendering is performed with the OASIS tool[5] which takes into account the topography of the objects, the geometric conditions of the observations provided by AURORA and the IFOV of MIRS. Cast shadows are accounted for in the tool. The Hapke model[7] with the parameters of [8] are used to compute the bidirectional reflectance. The surface temperature is calculated with the "Standard Thermal Model"[9], which allows us to add the thermal emission from the surface. Note that multiple reflections, thermal conductivity and self heating are not included. We also neglect the contribution of Mars to the surface temperature and reflected light from Phobos and Deimos. For Phobos, we used an updated version of the SPC shape model[10] with three fractal subdivisions in order to artificially increase the resolution of the shape model.

MIRS Instrument Modeling: MIRS is a pushbroom-based instrument made of two optical subsystems, separated by a slit in an intermediate focal plane[6] (Fig. 2). At each time step, this slit crops the spatial observed line, which is then spectrally dispersed by a grating, allowing the matrix detector to acquire all wavelengths in one MIRS image. This slit separation forbids assimilating the whole instrument as a convolution. Thence, we obtain the resulting image by simulating light propagation through the instrument.

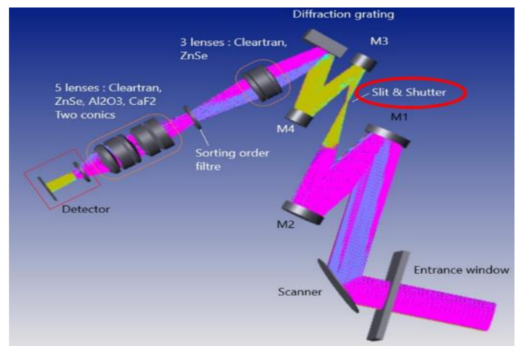

Figure 2. *MIRS optical configuration*

The light propagation is modelled by considering two simple optical subsystems, computing by Fourier Transform (FT) the convolutions in Fourier plane, including detectors effects with charge diffusion. However, we need to come back in focal plane to apply the slit mask on the light beam (Fig. 3).

Figure 3. *Principle of light propagation computation (yellow: Focal plane – green: Fourier plane)*

Because the slit is two pixels wide, there is a spatial/spectral mixing effect: for a given wavelength, two landscape lines are observed on the detector, and as a result, this wavelength overflows in the adjacent pixels associated with the nearby ones. This generates a blurring effect in the along-track direction (Fig. 4).

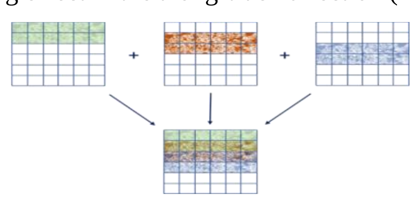

Figure 4. *Illustration of spectral/spatial mixing effect with three wavelengths*

The radiometric efficiency takes into account the high level of "background" signal, which is mainly due to the temperature of the spectrometer, emitting in the infrared range. This thermal signal generates a Poisson's noise, which is the main noise contributor, but all other sources of noise are also considered.

The geometric distortion is finally also modelled for the second optical part of the instrument, as it generates smile and keystone effects in the detector focal plane, so that the image is distorted (Fig. 5).

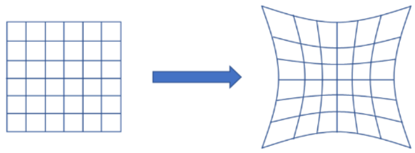

Figure 5. *Illustration of the distorsion*

Image Quality Performances: Such performances usually deal with signal to noise ratio (SNR) and Modulation Transfer Function (MTF). As detailed above, the instrument does not behave as a direct convolution, so that we must speak about "equivalent MTF", spatially as well as spectrally.

SNR. The requirement is quite high, and thus the mission programing needs to optimize the sun illumination and the phase angle during acquisitions[3]. In addition, on-board accumulations are needed to average the noise. Although a theoretical model has been used for the definition of the instrument, the simulations enable us to estimate the SNR (Fig. 6) and its variations along typical acquisitions, taking into account landscape variations computed by OASIS.

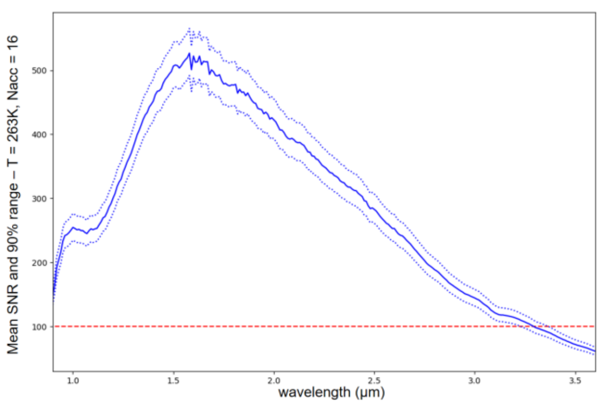

Figure 6. *Example of SNR along the spectral range*

Spatial Resolution. The equivalent MTF is computed by taking into account a broadband source point as an input of the simulation. Its value is mostly driven by the width of the slit (spectral/spatial mixing), the size of the pixels and their electronic diffusion, and the movement of the line of sight induced by the pushbroom acquisition principle. It is thus different in the across- and along-track directions (the first zero is reached at respectively 0.8 and 0.5 times the sampling frequency). It also strongly depends on the wavelength.

Spectral resolution. Basically, the main contributors are the same as for spatial resolution, except for the movement of the line of sight. Moreover, the spectral equivalent MTF (Fig. 7) is not dependent on the wavelength, but the varying spectral sampling leads to a resolution between 24.6nm and 26.4nm.

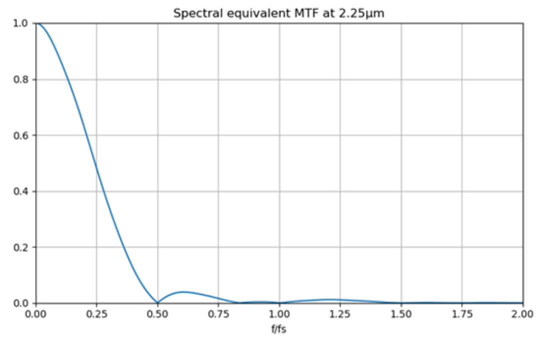

Figure 7. *Example of spectral equivalent MTF output*

A typical spectrum can thus be rendered (Fig. 8), considering the classical "blue" material for Phobos[2].

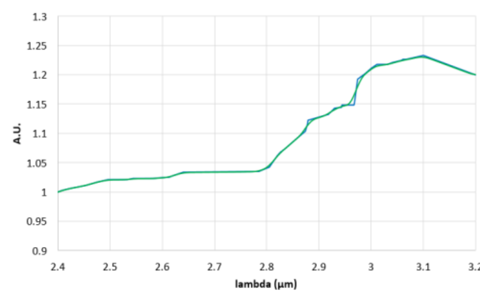

Figure 8. *Typical "blue" spectrum rendered by MIRS (blue: reference – green: rendered)*

Conclusion: Although theoretical, these simulations are a major asset to prepare the MMX mission. They improve our understanding of the underlying physical phenomena, which helps us to get a more accurate estimation of scientific products expected quality and will help us to analyse the in-flight data.

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References: [1] Nakamura T. et al., Earth, Plan. and Space, 73 (2021) 227-254. [2] Barucci M.A. et al, Earth, Plan. and Space, 73 (2021) 211-239. [3] Sawyer E. et al., 73rd International Astronautical Congress (2022), IAC-22-69391. [4] Goulet S. et al., 8th Eur. Mission Op. Data System Architecture Workshop (2021). [5] Jorda L. et al, SPIE Electronic Imaging Symposium, January 2010. [6] Barucci A. et al., 73rd International Astronautical Congress (2022) IAC-22-73342. [7] Hapke B., Icarus 67, 264, 1986. [8] Fraeman A.A. et al., JGR 117, E00J15, 2012. [9] Lebofsky et al., Icarus 63, 192, 1985. [10] Ernst C. et al., LPI 46, 2753, 2015.