ANALYSIS OF A THERMAL CORRECTION METHOD FOR THE MIRS INFRARED SPECTROMETER: PREPARATION FOR THE FUTURE OBSERVATIONS OF THE MARTIAN MOONS PHOBOS AND DEIMOS. G. David, M. Delbo, A. Barucci, F. Merlin, S. Fornasier, G. Poggiali, and P. Beck; LESIA, Observatoire de Paris, Université Paris Cité, Université PSL, Sorbonne Université, CNRS, 5 place Jules Janssen, 92190 Meudon, France; Laboratoire Lagrange, Observatoire de la Côte d’Azur, Université Côte d’Azur, CNRS, Nice, France; University of Leicester, School of Physics and Astronomy, University Road, LE1 7RH, Leicester, UK; Institut de Planétologie et d’Astrophysique de Grenoble, OSUG/CNRS, 122 rue de la piscine, F-38000 Grenoble, France

**Introduction:** The MIRS infrared spectrometer [1] is part of the scientific payload of JAXA’s Martian Moon eXploration (MMX) mission, which is bound to study the Martian system using remote sensing observations, delivering a rover for in-situ measurements of Phobos’ surface, and returning Phobos sample to Earth [2]. From the analysis of the reflected sunlight by the surfaces that MIRS will measure, it will be possible to provide information on the mineralogy and chemistry of Mars and its moons on a global scale. However, in the wavelength range covered by MIRS, i.e., between 0.9-3.6 μm, the spectrum includes the thermal emission from the surface, which can strongly modify the continuum of the spectra and the shape and intensity of the absorption bands if any. This thermal contribution needs to be modeled and removed to extract the compositional information carried by the reflected light. In this study, we develop a simple thermal emission correction model based on black body fit, with the objective of finding an efficient and rapid way to thermally correct the MIRS infrared data. We test the method to correct synthetic spectra generated using a thermophysical model, set to reproduce Phobos surface.

**Method:** The method used in this study consists of determining the effective temperature and emissivity $\epsilon$ from the spectra themselves and remove the thermal emission to retrieve the signal of the surface reflectance. We used the approach developed by [3] that was originally developed to correct the Moon Mineralogy Mapper observations. This approach is an iterative method and uses the assumption that the continuum of the reflected solar component is approximately linear beyond 2.5 μm. The signal at shorter wavelengths (where the thermal contribution can be assumed negligible) is used to extrapolate the reflected component in the part of the spectrum where the thermal emission becomes important, which enables us to make the distinction between the reflected and thermal contribution. For the first iteration, a linear fit is performed between 2.1 and 2.3 μm and then extrapolated to 3.5 μm. The differences between the extrapolated reflectance and the original spectra at 3.5 μm are assumed to be due to the thermal contribution, and the temperature $T$ multiplied by the emissivity is varied until the best fit with the thermal emission contribution is obtained. Emissivities are determined by using the projected I/F (i.e., the signal collected by the instrument normalized to the solar flux) at a specific wavelength and Kirchhoff’s law ($\epsilon = 1/I/F$). Obtained an estimation of the thermal contribution, it is removed from the signal given a first corrected spectrum. From this latter, a second iteration is performed with a new extrapolation of the continuum between 2.6 and 2.9 μm at 3.5 μm given a new estimation of the thermal contribution. While in the first iteration, emissivity is considered as constant with wavelength, the second iteration will consider a wavelength-dependent emissivity, in addition to incidence angle correction (i.e., by dividing reflectance by the cosine of solar incidence angle). The method will perform up to three iterations, using each time the previously corrected spectrum. If the temperature retrieval of the first and second iterations is within 1 K, then the third iteration is not performed. More details can be found in [3].

**Data:** The model is tested on synthetic data of Phobos, simulated using a thermophysical model [4], which calculates thermal infrared spectra of airless bodies, as a function of several physical parameters such as albedo, roughness, thermal inertia, rotation period, direction of the rotation axis, illumination and viewing geometry. Three different spectral datasets were generated, namely: (1) a first dataset consisting of seven synthetic spectra (from 0.5 to 3.69 μm) in nadir view for which the thermal emission contribution was calculated at different temperatures from 262 K to 329 K; (2) in a second dataset, the effect of roughness was generated by adding hemispherical section craters on the facet (see e.g., [4]). Each sub-facet contributes to the thermal infrared flux with its own temperature, which depends of the geometry relative to the sun, shadowing, and mutual heating [5]; (3) in a third dataset, we generated 6 spectra with the same parameters as before, but we also added a synthetic absorption band centered at 3.2 μm (mimicking the presence of organic species), to study its effect on thermal emission correction, and our ability to retrieve the band after the correction. Finally, for each of these previous datasets, 50 spectra are also generated by adding a Gaussian noise, with a signal-to-noise ratio of 100 to approach the data that will be acquired by the MIRS instrument on Phobos. To determine the error of the thermal emission correction, we quantified the diffe-
The first column shows the synthetic I/F including the thermal contribution (red lines), the reference synthetic I/F without the thermal contribution (green lines), the I/F after removal of the thermal contribution by the method after the first iteration (first blue lines), the second iteration and third iteration (purple lines). The dashed curves represent blackbody radiation functions at the temperatures estimated from the synthetic data at the different stages (color coded as before). These functions are subtracted from the original synthetic I/F to obtain the thermal emission corrected I/F. The middle column shows a zoomed-in version of the corrected spectra (color coded as before). The right column displays the absolute percentage error (APE) value between the different thermal emission corrected I/F spectra and the original simulated I/F without the thermal emission. Upper plots (a, b, c) correspond to the spectrum simulated from a facet that includes a combination of the emission of different surface elements, which have different temperatures. Lower plots (d, e, f) correspond to the same spectrum, which also includes an absorption band centered at 3.2 \( \mu \)m.

**Results:** Our results show that this simple method gives at first order relatively good results despite under-corrections are observed in all our simulations leading to a small rise of the reflectance at the red edge of the spectra (e.g., Figure 1b, e). Based on all our simulations, we found for the third and final iteration that errors in the thermal tail correction are always lower than 5.0% for wavelengths lower than 3.5 \( \mu \)m. We observed that thermal correction residues are significantly reduced when the number of iterations increases. Consequently, by improving the correction with the second and then the third iteration of the data treatment, we confirmed the efficiency of the iterative approach compared with using a single continuum extrapolation and a blackbody fit. We found a good accuracy of the correction method in the most useful part of the infrared spectrum, where the signature of several species could be observed such as hydrated silicate minerals (feature at 2.7-2.8 \( \mu \)m), water ice (absorption band around 3.0 \( \mu \)m) or organic materials (3.2-3.5 \( \mu \)m). Beyond 3.5 \( \mu \)m, we found among our simulations that the maximum error in the thermal tail correction can be relatively high, and can reach up to 10.0% (at \( \lambda = 3.69 \)\( \mu \)m) in our worst case. When an absorption band is located in the thermal part of spectra at 3.2 \( \mu \)m, we found that the model is still robust and still gives good outcomes for the correction of the entire spectrum (Figure 1d,e,f). If the strength of the absorption band is preserved in most cases for the last iteration, it can be sometimes overestimated by an order of magnitude of a few percent (Figure 1f). Finally, we observed that the method does not collapse when the data are noisy (SNR= 100). Although the error after correction slightly increases, it remains minor and limited to a few percent.

**Conclusion:** From this thermal correction method, we conclude that we can be confident in correcting the thermal tail of future MIRS data (and other infrared spectral data) with this method in the spectral range 0.9-3.5 \( \mu \)m. The method is suitable for future MIRS observations and could be used at least during the early stage of the MMX mission, for which shape model of the martian moons with sufficient spatial resolution will not be available yet, which makes it impossible to use more sophisticated methods (e.g., modeling using photometric functions). Although simplistic, this empirical thermal correction can be used to make a first quick analysis and interpretation of the infrared data obtained by MIRS, especially during the pivotal and quick initial phase of global mapping, and characterization of the potential sampling sites.

**References:**