Analysis of a thermal correction method for future MIRS observations on Phobos and Deimos

G. David[1], A. M. Barucci[1], M. Delbo[2], F. Merlin[1], P. Beck[3], S. Fornasier[1] and G. Poggiali[1]

[1] LESIA, Observatoire de Paris, Université Paris Cité, Université PSL, Sorbonne Université, CNRS, Meudon, France
[2] Laboratoire Lagrange, Observatoire de la Côte d'Azur, Université Côte d'Azur, CNRS, Nice, France
[3] Institut de Planétologie et d'Astrophysique de Grenoble, OSUG/CNRS, 122 rue de la piscine, F-38000 Grenoble, France

Contexte :

The Martian Moon eXploration (MMX) mission is scheduled to be launched to the Martian system in 2024 [1]. It will carry the MIRS instrument [2], an infrared imaging spectrometer dedicated to the study of Mars and its two satellites: Phobos and Deimos. In the spectral range covered by MIRS (0.9-3.6 μm), several components of geological interest will be studied such as anhydrous and hydrous silicate minerals, water ice and organic matter. Determining the formation processes of the Martian moons requires to constrain the presence and relative abundance of these phases through their spectral properties.

Objectif :

Issue: In the spectral region beyond ~2.5 μm, the signal collected by MIRS is a combination of reflected sunlight and thermal emission from the observed surfaces. The thermal emission can strongly modify the continuum of the spectra (e.g., Fig. 1).

A thermal emission correction is needed before proceeding to the mineralogical analysis of MIRS data. In this study, a simple method is tested on synthetic data of Phobos to evaluate its potential and limitations.

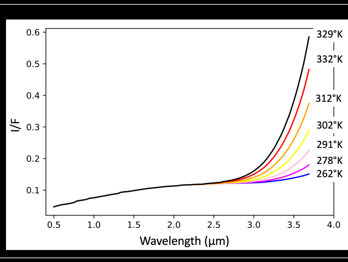

Fig 1. Synthetic spectra of Phobos generated by means of a thermo-physical model [3] showing the effect of the thermal emission for different temperatures. For wavelength higher than ~2.5 µm and high temperatures, this contribution is dominant compared to the reflected solar fraction

Method and data :

The thermal tails of spectra are mainly controlled by the surface temperatures and emissivity. These parameters are often not well-constrained on planetary surfaces but they can be estimated directly from infrared spectra.

In this work, we explored an empirical method of thermal tail removal, based on Planck blackbody fit, originally developed by [4].

This iterative method assumes that the continuum of the reflected sunlight is approximately linear beyond 2.5 μm enabling extrapolation of the reflected component in the thermal part of the spectra at a given wavelength.
The thermal contribution is then fitted with a blackbody Planck function radiation, and a temperature can be derived.

Emissivity (ε) is determined by using the projected I/F at a specific wavelength and Kirchhoff's law (ε=1-I/F). Two iterations are performed to adjust the temperature, using in the second run the previous corrected spectra.

To test the model, different spectral datasets analogous to Phobos were generated by means of a thermophysical model [3] :

- First, seven synthetic reflectance spectra with a thermal contribution at different temperatures from 262 K to 329 K have been generated. Here, the scene is relatively straightforward and corresponds to a flat facet in nadir view.
- For the second dataset, roughness has been generated by adding hemispherical section craters into the facet. Each sub-facet contributes to the thermal infrared flux with its own temperature, which depends on the geometry relative to the sun.
- In addition to roughness, the third dataset includes a fictitious absorption band centered at 3.2 μm, to study its effect on thermal correction.

The efficiency of the correction is determined with the Mean Absolute Percentage Error:

$$\text{MAPE} = \sum_{\lambda>2.5}^{n} \square m \left|\frac{y_\lambda - x_\lambda}{y_\lambda}\right| \frac{100}{n}$$

where y_λ and x_λ are the I/F values of the reference and corrected spectra for each wavelength in the thermal part (i.e., λ>2.5 μm).

Results :

The first dataset is used to test the temperature retrieval of the model.
An average of around 1K of difference from the true temperature was found (Fig.2). These results are consistent with the experiment made by [4], who found a similar result with heated basalt in the laboratory.

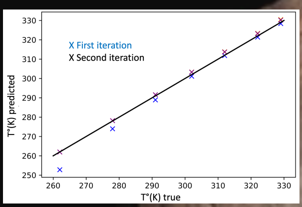

Fig 2. Plot showing the temperature used as input for the thermophysical model as a function of the temperatures retrieved by the thermal correction model.

The first dataset has corrected spectra with respectively MAPE scores of ~1.25% (σ=0.5 %) and ~0.21% (σ=0.2%) on average for the first and second iterations, which is pretty good.

For the second dataset, a small under-correction is observed (Fig.3, left panel) but this residual thermal contribution is quite negligible as expressed by the good MAPE scores (μ~3.1%, σ=1.1%, first iteration; μ~1%, σ=0.49%, second iteration).

In all simulations, the emissivity predicted by the model is also very consistent with the one used in the thermophysical model (ε=0.9) to generate the data.

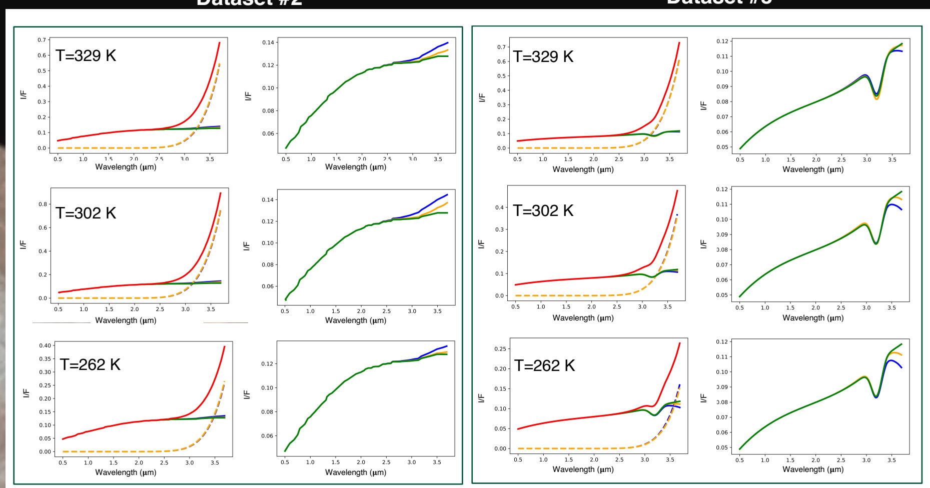

Fig 3. Spectra with thermal emission (red lines) are compared to the two iterations of thermal removal (first and second iterations are represented respectively in blue and orange). Green spectra correspond to the synthetic spectra simulated without the thermal contribution and they serve as a benchmark. Dash lines correspond to the Planck functions of the first and second iterations (respectively in blue and orange). The left panel shows the results for the second set of synthetic data, whereas the right panel corresponds to the third dataset with absorption bands.

For the spectra containing an absorption band at 3.2 μm, the model of thermal correction seems to be still relatively efficient (Fig. 3, right panel).

The MAPE scores of these spectra remain quite good (μ~1.6%, σ=0.61%, first iteration; μ~0.8%, σ=0.01 %, second iteration). However, a drop in reflectance can be observed at the edge of the spectra (above 3.45 μm).

In terms of band depths, the differences with the references are on averages equivalent to ~7.3% (σ=0.96%) and ~4.7% (σ=4.2%) for spectra corrected with one and two iterations.

Conclusion :

We tested on synthetic infrared spectra of Phobos, the thermal correction method developed by [4]

- This method seems to be efficient for the thermal correction of future MIRS observations, with a relatively low error
- By improving the MAPE scores with the second run of the data treatment, we confirmed the efficiency of the iterative approach
- Emissivity retrieved by the model is good
- Overestimation of the band depths located on the thermal spectral region is limited to a few percent

Future works need to simulate noise in our data with an SNR similar to future MIRS observations to confirm the robustness of the method

References : [1] Kuramoto, K., et al., (2021), Earth Planets Space. 74(1), 1-31. [2] Barucci, M. A., et al., (2021), Earth, Planets, and Space. 73-211. [3] Delbo, M., et al., (2015), Asteroids IV, 1, 107-128. [4] Clark, R. N., et al., (2011), Journal of Geophysical Research: Planets, 116(E6).