COMBINING A NON LINEAR UNMIXING MODEL AND THE TETRACORDER ALGORITHM: APPLICATION TO THE ISM DATASET.

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Introduction: Feature matching algorithms are largely used to analyze the datasets of imaging spectrometers. The Tetracorder algorithm [1] is one method based on this principle. This freely available algorithm takes as input a spectral library, for which diagnostic features have been defined: a diagnostic feature is an absorption band which needs to be present in a spectrum for the identification of a mineral. Tetracorder fits each spectrum of the dataset with the defined diagnostic features, after continuum removal, and attributes the mineralogy of the best obtained fit. This very powerful method has been applied successfully on AVIRIS observations of the complex hydrothermal mineralogy of Cuprite NV and of the summit of Mauna Kea, HW ([1, 2]). This algorithm is fast and efficient. However, while the spectra of planetary surfaces are complex nonlinear functions of grain sizes, relative abundances, material opacity, and types of surfaces (dust, outcrops, sand), Tetracorder, as any feature matching algorithm, can only identify minerals of the input spectral library, which limits the interpretation in terms of geology.

It is well recognized that radiative transfer theories can provide approximate solutions of the interactions between light and a particulate compact medium. By using this approach, we can expect to explore the whole space of parameters to derive quantitative results on the surface composition. The Shkuratov theory [3] has recently been adapted for the analysis of infrared spectra of planetary surfaces [4]. It was successfully tested on laboratory mixtures ([4]), compared with Hapke theory ([5]), and applied on the ISM observation of western Syrtis Major ([6]).

In this work, we combine the two methods to identify and map the mineralogy on Mars in some regions observed by ISM/Phobos2. Synthetic spectra of a sample of possible mineralogies on Mars are calculated using our non linear unmixing model ([5]). We add these spectra to the input library used by Tetracorder, and apply the algorithm on six observations acquired by ISM.

Data processing: Our unmixing algorithm [5] allows the modeling of 3 types of mixtures: intimate mixtures of coarse particles (>> λ), mixtures of dusty particles (<<λ), and outcrops. These 3 types of mixture can be spatially combined. We used the spectral unmixing model to calculate several hundred spectra of mixtures of low calcium pyroxene (LCP), high calcium pyroxene (HCP), olivine, feldspar, and hematite. These endmembers are believed to be representative minerals of the dark Martian regions [7,8,9,6]. Four different types of mixtures are used: the first two sets consist of mixtures of fine particles of hematite (called dust hereafter) with coarse particles of orthopyroxene, clinopyroxene and olivine with grain sizes of 50 µm and 200 µm respectively. We create spectra of the possible mineralogical concentrations of the four minerals, by steps of 10%. The third set of spectra aims at modeling basaltic sand or basaltic bedrock: we model mixtures of LCP, HCP, olivine, and feldspar with a 200 µm grain size. In basalt on Earth, feldspar contains inclusions of small grains of iron oxides. We add inclusions of small grains of hematite in the feldspar, with concentrations comprised between 1 and 10%. The fourth set of spectra is based on the results of [6]. The modeling of 150 ISM spectra in Western Syrtis Major led to the conclusion that the spectra were best modeled with a mixture of LCP with a mean grain size of 20 µm, HCP with a mean grain size of 30 µm, olivine with a mean grain size of 500 µm, and very small grains (dust) of hematite in different proportions. We added the four sets of spectra to the USGS library initially used by the Tetracorder algorithm. Note that we do not take into account the geomorphology, which has been demonstrated to be important in such studies ([6]).

We limit our investigations to olivine contents lower than 15% of the total concentration of coarse grain materials. Several investigations showed that olivine, if present, has a very low concentration [10, 11].

For each of the spectra we created, we defined one or two diagnostic features: the 1 µm band was considered as the first diagnostic feature. The second diagnostic feature, the 2 µm band due to LCP and HCP, was added only if the feature was deeper than 5%.

We applied the algorithm to six observations acquired by the ISM/Phobos2 imaging spectrometer. The spectra were corrected from the aerosol contribution following [12].

Results: The map resulting from the application of Tetracorder on the ISM dataset is presented in fig 1.

The bright regions are mapped as hematite by the Tetracorder algorithm, which is consistent with the 0.86 µm absorption band identified in these regions ([13]).

The center of Syrtis Major, and the really mafic parts of Valles Marineris present deep absorption bands at 1 and 2 µm. The algorithm returns a abundant high- (30-40%) and low-calcium pyroxene (20%) in these regions, in agreement with the measured mineralogy of the SNC meteorites [14]. This result is consistent with [7] and [8] who noticed that a composition similar to the composition of the basaltic SNCs could be the dominant mineralogy at the surface of Mars.

As already identified by [10], the composition of the eastern part of Syrtis Major is different from its western part. No feldspar is mapped in Western Syrtis Major while a concentration of 30-40% is identified by the algorithm in Eastern Syrtis.

Far Eastern Syrtis and the western part of Valles Marineris are mapped as a mixture of 20% HCP, 10% LCP, 70% feldspar with 5% hematite in inclusion in the feldspar matrix. This result is in agreement with TES results for the basaltic endmember ([11, 15]): the proportion of HCP of 21% expected by [11] coincides with our 20%, and our 10% LCP is in agreement with the possible 9% of [11]. Our concentration in feldspar (70%) is higher than the expected 55% of [11], but the feldspar signature at 1.2 µm is not very diagnostic, and an overestimation can reflect the presence of other minerals with shallow signatures in the near infrared, which have the property to reduce the spectral contrast such as glass or a dark component (oxide). However, the absorptions in these regions are very shallow, and this result may be due to an artifact of the algorithm, which identifies high concentrations of feldspar to reduce spectral contrast.

Conclusion: The application of our nonlinear unmixing modeling ([5]) to create a spectral library of series of mixtures of minerals, and the subsequent application of the Tetracorder algorithm, allows to map the mineralogy in the ISM/Phobos2 dataset, in the limit of the input spectral library. In the near future, we will investigate further which mineralogical associations have to be included in the library, so as to prepare the application of the method to the forthcoming OMEGA dataset.

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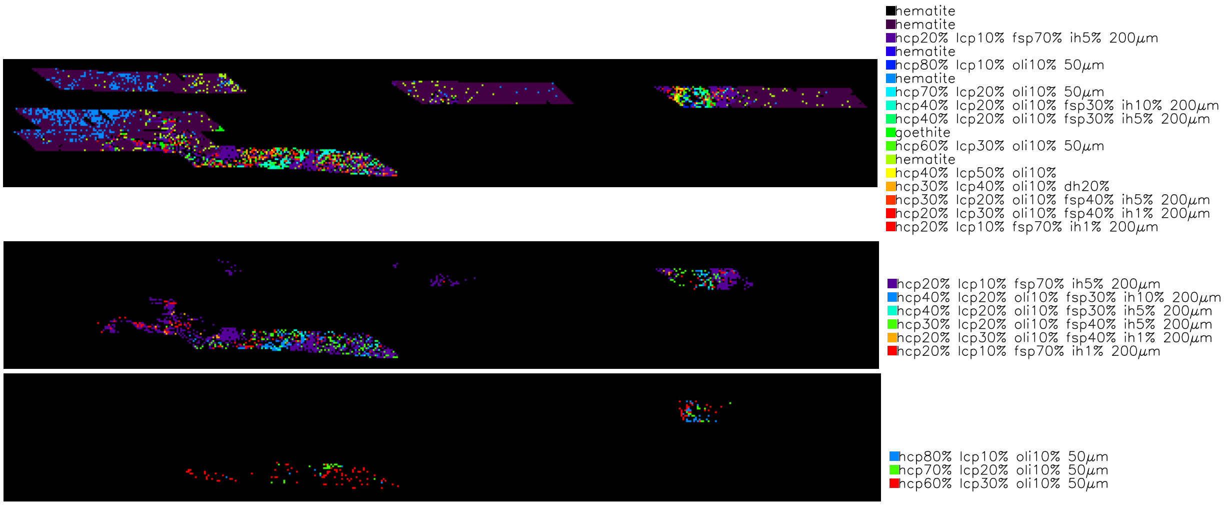

Fig 1: result of the application of our method on six ISM observation sessions. The coordinates of the lower left corner are (62W, 20S), and the coordinates of the top right corner are (239W, 15N). Top: all the different identified classes are represented. Middle: classes corresponding to a mixture of clinopyroxene, orthopyroxene, olivine and feldspar with inclusions of hematite. Bottom: classes corresponding to mixtures of clinopyroxene, orthopyroxene, olivine with grain sizes of 50 µm, and hematitic dust. The relative proportions of the minerals are indicated on the right. The labels on the right represent the mineralogical content: we show the concentrations of high calcium pyroxene (hcp), low calcium pyroxene (lcp), olivine (oli), feldspar (fsp), hematite as inclusion in the feldspar (ih), or as dust (dh). The grain size of low calcium pyroxene, high calcium pyroxene, olivine and feldspar is indicated at the end of the label.