LABORATORY HYPERSPECTRAL STUDY OF ICE AND MARS SOIL SIMULANT ASSOCIATIONS. COMPARISON WITH CRISM OBSERVATIONS OF ICY SURFACES.

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Context: Ices are found over a wide range latitudes across the surface of Mars, whether they are H_2O or CO_2. They undergo diurnal [1, 2] and seasonal [3] cycles by sublimating into the atmosphere and condensing in the atmosphere or at colder parts of the surface. Depending on the atmospheric and surface conditions -mainly temperature and partial pressure-, ices will appear under various forms and will be associated in different ways with the substrate (e.g. as frost or slab), either ice or regolith. Spectral or color imaging and reflectance spectrometry stand out as the techniques of choice to identify ices on the surface and/or to characterize their association mode with the regolith. Examples of spectrometers and imagers that track ices on the surface of Mars are the OMEGA imaging spectrometer, the stereo and color camera HRSC, the imaging spectrometer CRISM and the color camera HiRISE. As from the first quarter of 2018, a new camera will be added to this list: the Colour and Stereo Surface Imaging System (CaSSIS) [4], onboard ESA's Trace Gas Orbiter (TGO). With four color bands (BLU: 475 nm; PAN: 650 nm; RED: 850 nm; NIR: 950 nm), CaSSIS will ideally complement the datasets collected by other cameras thanks to its high signal-to-noise ratio and the non-Sun-synchronous orbit that TGO will follow around Mars. We thus expect to be able to observe both seasonal and diurnal phenomena (such as H_2O and CO_2 frosts) in good conditions.

Problematic: Unfortunately**,** the interpretation of the observations of the Martian surface in terms of detection and quantification of ices is not straightforward, since many parameters control the shape of the spectra and color of the surface, e.g. shape and size of the particles, albedo of the surface, presence of hydrated minerals, relative content of ice and/or type of association of the ice with the surface. In order to help with the understanding of past and future observations, we have conducted a series of experiments to study the visible and near-infrared spectro-photometric signatures of different ice and regolith simulant associations. We have produced a wide range of samples to cover parameters of interest, i.e. type of ice and substrate, particle sizes, substrate-ice association modes and ice concentration, and we have characterized them through hyperspectral imaging. Next, we have analyzed the spectra and simulated colors of the samples as would be seen with CaSSIS, to identify key and discriminative features. Finally, as a way of assessing the pertinence of applying our results to Martian observations, we have compared our laboratory data with CRISM measurements of icy surfaces.

Samples and methods: As dry members for our associations, we have used the Martian soil simulant JSCM-1 [5], that matches average reflectance of the bright plains of Mars, and also a darker basalt [6] in order to match terrains that show lower albedo, such as the ones observed where Phoenix landed. The bulk of our ice analogs are made of H_2O. Two different water ice size particles (SPIPA-A, 4 µm of mean diameter and SPIPA-B; 70 µm) have been intimately mixed with the soil simulants (as done in [7]). Atmospheric water has been condensed onto the simulants in order to study frost, and dusty samples have been saturated with water and frozen to simulate frozen soils. We have also tested new protocols for the production of granular carbon dioxide ice and posterior mixing with soil simulant, and we have conducted measurements on CO_2 ice slabs.

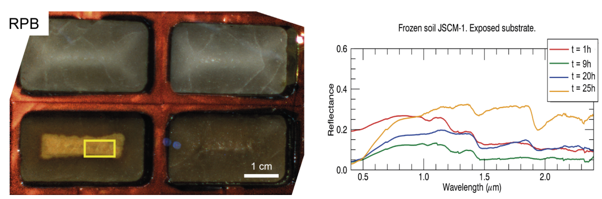

Figure 1. Left: RED-PAN-BLU CaSSIS color composite pictures of four JSCM-1 frozen soils after 25h of sublimation. Right: evolution of the reflectance spectra of the area indicated by the yellow square.

The hyperspectral cubes have been acquired at the Laboratory for Outflow Studies of Sublimating icy materials (LOSSy) with the Simulation Chamber for Imaging the Temporal Evolution of Analogue Samples (SCITEAS) [8]. This chamber is designed to measure the reflectance of samples from 0.355 to 2.5 µm, at low temperature and pressure conditions. We have characterized the spectra by studying and comparing various spectral criteria. For instance, we have measured the reflectance of the continuum at 0.8 µm and compared it to the strength of the absorption band of H_2O at 1.5 µm (computed as in [9]). On the other hand, we have convolved the reflectance spectra with the spectral response of CaSSIS [10] in order to produce simulate color images and compute color ratios. Figure 1 shows pictures of four JSCM-1 frozen soils after 25 hours at low temperature and pressure conditions. Figure 1 shows a false-color three-band image composed by the channels RED-PAN-BLU of CaSSIS as well as the evolution of the reflectance spectra of the area indicated with a yellow square. On that area, the ice initially covering the JSCM-1 has sublimated with time, changing significantly the reflectance and spectra of the surface. Lastly, we have conducted the same spectral analysis on a temporal series of CRISM observations of a Martian polar region (85º N and 0º E), obtained during two consecutive Martian springs (Martian years (MY) 29 and 30). An analysis of these data was already published in [11], where this region was informally referred to as "Kolhar".

Results and discussion: Figure 2 shows the reflectance at 0.8 µm versus the strength of the absorption band of water at 1.5 µm for different ice and soil simulant associations. We see how the measurements corresponding to water frost samples can be differentiated from the ones involving other forms of water ice. This fact consolidates with the increasing presence of ice in the sample, indicated by the blue arrows. Fig. 2 also evinces that our granular CO_2 samples cold-trapped atmospheric water.

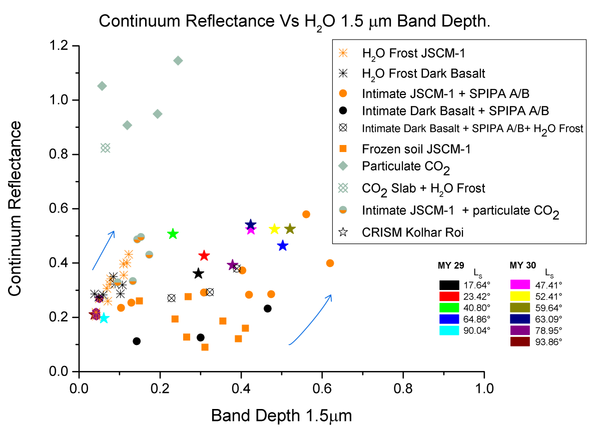

Figure 2: Continuum reflectance versus the depth of H_2O 1.5-µm absorption band (experimental and CRISM data). For experimental data, different colors correspond to the substrate and different symbols indicate the ice/dust association. The colors of the CRISM points (stars) indicate the time the observations were made, which are detailed in the legend for both MY 29 and 30.

CRISM measurements fall within our experimental data, which suggests that our experiments, even without fully replicating the Martian conditions, are suitable for comparison with Martian observations. The evolution of the surface that can be deducted from the position of the CRISM points in Fig. 2 coincides with the one provided by other studies such as [9, 12, 11]; during early spring the surface of the seasonal cap is dominated by CO_2 ice and contaminated by H_2O frost and bright dust. A following increase in the reflectance of about 50% suggests that dust is progressively being removed from the ice. After mid-spring, the signature of water ice peaks, to finally reach a minimum around the summer solstice. In general, CRISM points fall in the vicinity of the points for laboratory intimate mixtures. Figure 3 shows the BLU/RED color band ratio of our samples as would be measured with CaSSIS.

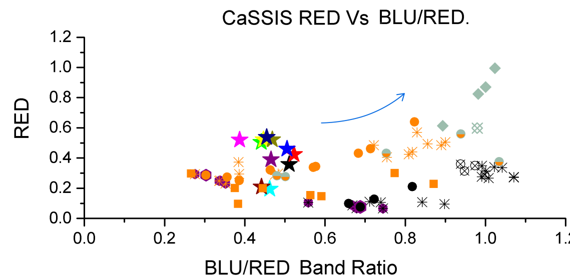

Figure 3: Reflectance measured in the CaSSIS RED filter versus the BLU/RED color ratio. The legend of Fig. 2 applies.

The majority of the observations made with CRISM do not fall on the trend drafted by the experimental data, with the exception of the CRISM points corresponding to the Martian summer (Ls = 90.04º and Ls=93.86º); we will address this discrepancy in detail. Both figures underline the importance of conducting further experiments with CO_2 ice and dust mixtures, which are being already conducted at LOSSy.

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