Sublimation at Grain Boundaries of Polycrystalline CO2 Slab Ice: The Clue to the Strong Spring Albedo Increase of the Martian Seasonal Polar Caps

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SUBLIMATION AT GRAIN BOUNDARIES OF POLYCRYSTALLINE CO_2 SLAB ICE: THE CLUE TO THE STRONG SPRING ALBEDO INCREASE OF THE MARTIAN SEASONAL POLAR CAPS

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Introduction: Understanding the microphysical processes occurring on the Martian seasonal cap is critical since their radiative properties can affect the Martian climate. The albedo increase of the Martian seasonal caps during spring is a well-documented phenomenon, Fig.1 [1]. Several processes have been proposed as an explanation for these observations: the decrease of the CO_2 grain size [2], a cleaning process of the CO_2 slab that would imply either the sinking or the ejection of the dust contained in the ice ([1], [2], [3]), a water layer accumulation on the top of the slab [3], the role played by aerosols [2] etc. So far, no experimental simulations have been realized to discriminate between these processes. We designed experiments to investigate some of these hypotheses, as well as a few others: CO_2 ice grain size decrease through thermal cracking, dust segregation by heating ice, grain changes during ice sublimation, ...

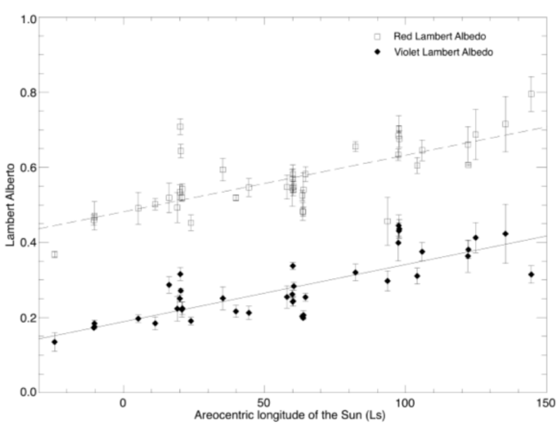

Figure 1: Albedo increase of the Northern seasonal cap seen by Hubble [1]

Experiment protocol: To simulate Martian seasonal deposits, a pure CO_2 ice and an homogenous mixture of CO_2 ice and dust have been produced over a layer of dust in the Carbo-NIR cell, the chamber developed at IPAG to simulate Martian environment. CO_2 ice is obtained in a granular form and then 'slabized' (transformed into polycrystalline ice) in the cell using CO_2 gas injection [4]. The entire experiment has been performed at a temperature of 150 K and a pressure of 6.5 mbar, characteristic of the Martian environment during winter. The dust used in this experiment is a volcanic tuff that which is used as an analog for Martian dust in this experiment. It has been characterized by reflectance spectroscopy ([5], [6]).

Reflectance spectra were acquired with the Spectro-gonio radiometer SHINE at IPAG laboratory [7]. Our measurements span the 0.5-4 µm range with a spectral sampling of 20 nm between 0.5 and 1 µm and 10 nm between 1 and 4 µm. The spectral resolution varies along the spectrum : from 19 nm between 0.5–3 µm to 39 nm between 3–4 µm. All the spectra were acquired with nadir illumination and an emergence angle of 15°.

On Mars thermal stress induced cracking could be produced by a thermal gradient inside fragile slab ice. This thermal gradient could either be positive and induced by the absorption of solar energy or, negative and created during atmospheric depression conditions, by the rapid cooling of the surface to equilibrate with the CO_2 vapor pressure.

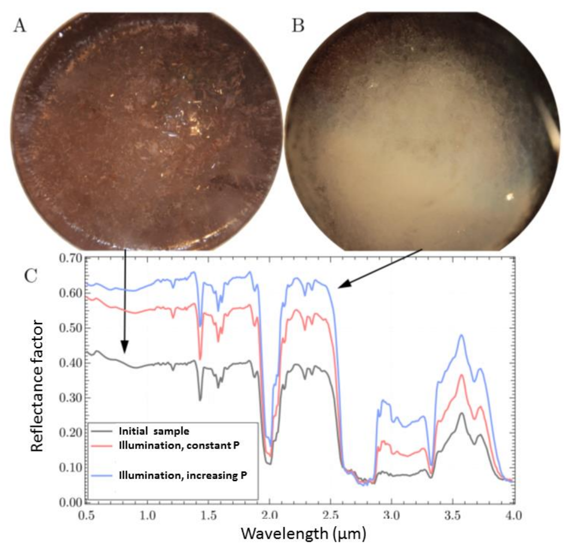

Figure 2: Bidirectional reflectance spectra of the CO_2 slab initial state (black), after thermal cracking (red) and after cracking only due to thermal stress (blue).

Both situations were tested during several experiments, including: illumination with a stable pressure, decrease of pressure, illumination with a pressure increase. The first situation represent the best Martian analogy since we pumped into the limited volume of the cell to keep a stable CO_2 gas pressure all along the experiment to simulate a stable atmosphere. In the second case with decreasing pressure, we investigated typical ΔP experienced in Mars atmosphere with baroclinic waves activity (typically 0.5-1 mbar). In our simulations, illumination is provided by an halogen lamp and the flux at the sample is equal to the flux received by seasonal deposits in early spring (around 200W.m^{-2}).

Results: Fig.2 presents bidirectional reflectance spectra of the sample before and after some of the experiments. The black one is a typical dirty slab spectrum obtained in our cell with deep CO_2 bands and a low reflectance. The blue and red spectra are obtained after subjecting the slab sample to sublimation and to a thermal gradient with 2 different protocols : thermal gradient for the red spectrum was produced using illumination + pumping (stable P and surface T) while the thermal gradient for the blue spectrum is realized with illumination only (i.e. the pressure increased inside the cell as the sample warmed up). Results associated with pumping only (ΔP = 1 mbar) are not displayed since we didn't observed any reflectance change using this method. At 1 μm, the reflectance is increased by 41% on the red spectrum and 58% on the blue spectrum. The difference of albedo increase between both cases is simply due to a longer illumination time for the second case (2h instead of 1h). This albedo increase is comparable with the one observed on Mars (see Fig.1).

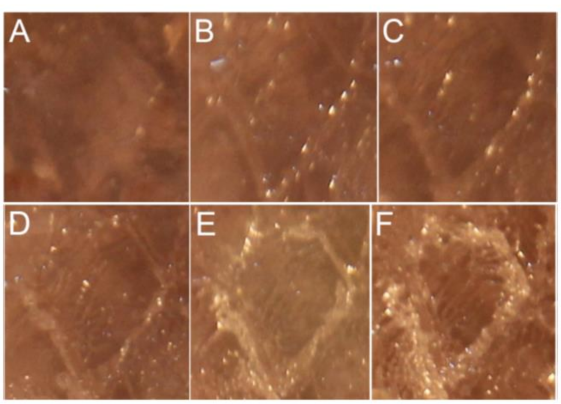

Figure 3: Morphological evolution of CO2 ice grain. During sublimation the grain boundary that separate this grain from the others become brighter.

From the side observation of the sample we first observed that the dust contained into slab ice don't accumulate on the surface and rather 'sink' slowly (2mm/day) into the slab, as proposed by some authors since dust preferably absorb light compared to CO_2 ice, warm and sublimate the ice around it. However this produce only very limited changes in reflectance.

Thermal cracking of CO_2 slab ice also seems to be unable to produce a significant albedo increase as these mechanical cracks inside the slab are rapidly eliminated.

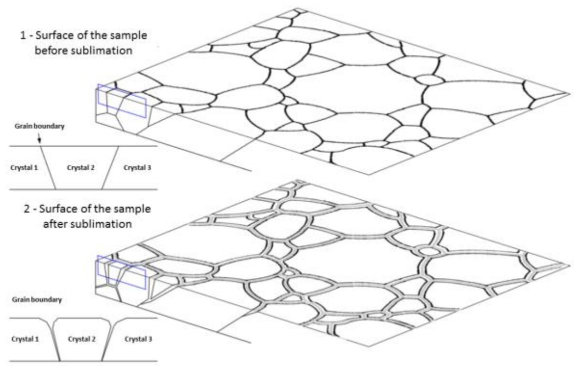

Figure 4: Schematic of the evolution of the sample surface subjected to illumination.

On the other hand the process that clearly produce the brightening of the slab is the sublimation of the ice at the grain boundaries of the polycrystalline ice that progressively open and deepen them (Figure 3). When the poorly reflecting ice/ice interfaces are replaced by a pair of ice-gas + gas-ice interfaces they reflect light more than an order of magnitude more (Figure 4).

Conclusion: These experiments showed that dust sinking and thermal slab cracking are not efficient at increasing the reflectance but that sublimation of CO_2 slab ice can readily produce a strong increase of the reflectance (as high as 60%). The microphysical process involved is the progressive opening of the grain boundaries. The magnitude of the measured effect is consistent with the increase observed on the Martian seasonal condensate and can mimic the photometric behavior during spring.

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