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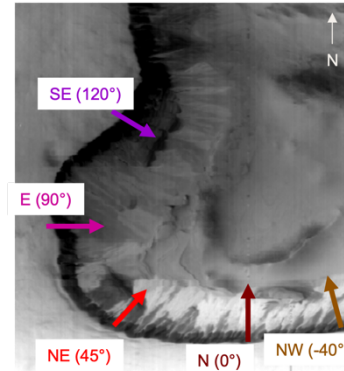
**CO<sub>2</sub> Ice Properties and Structure using CRISM Data: a Glimpse into the Formation Mechanism of Martian Gullies.** A. Leclef<sup>1</sup>, M. Vincendon<sup>1</sup>, C. Lantz<sup>1</sup>, S. J. Conway<sup>2</sup>, M. Massé<sup>2</sup>, K. Pasquon<sup>2</sup>.<sup>1</sup>Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, 91400 Orsay, France ([apolline.leclef@universite-paris-saclay.fr](mailto:apolline.leclef@universite-paris-saclay.fr)). <sup>2</sup>Laboratoire de Planétologie et Géosciences, Université de Nantes, CNRS, France.

**Introduction:** “Gullies”, distinctive slope flow structures, have been identified on Mars [1] and resemble gullies on Earth carved by liquid water. They have a notable concentration at the mid to high latitudes, and particularly those with present-day activity are found where there is a seasonal presence of surface ice [2]. Three main ice-related mechanisms for gully formation have been discussed so far: a) water ice transitioning into a liquid state and flowing down the hillslopes [3]; b) transparent/translucent layer of dry ice (CO<sub>2</sub> ice) forming CO<sub>2</sub> geysers under the sun’s heat [4]; c) granular CO<sub>2</sub> ice triggering dry avalanches and/or fluidizing the regolith with the gas released [5]. Recent studies favor a dominant role for CO<sub>2</sub> ice in the formation of gullies [2, 6]. Investigating the composition and properties of Martian ices, notably CO<sub>2</sub> ice, may thus help to constrain the formation mechanisms of martian gullies.

This study seeks to develop a model to characterize the properties of CO<sub>2</sub> ice at Sisyphi Cavi (see Fig. 1), a location where active gullies have been previously reported and studied [7]. Our goal is to determine to what extent CO<sub>2</sub> ice is transparent or granular, as this property differentiates type “b” mechanisms from type “c”. We use data from CRISM instrument aboard the Mars Reconnaissance Orbiter’s (MRO) mission (NASA) to provide observational constraints on the properties of CO<sub>2</sub> ice from spectroscopy.

**Methods:** CO<sub>2</sub> ice spectra from the CRISM instrument are modeled under the assumption that CO<sub>2</sub> ice is transparent. A CO<sub>2</sub> ice thickness is thereby inferred, and this thickness is then compared to predictions of ice thicknesses by a climatological model to evaluate the relevance of the transparent ice hypothesis (a similar approach was employed by [8] for another location). One of the specific features of the work carried out here is the use of several azimuthal orientations (Fig. 1), as ice thickness depends on slope orientation (it is thicker on pole facing slopes and thinner on equator facing slopes). This will enable a relative analysis of the ice’s behavior in order to overcome uncertainties in the absolute ice thickness predicted by the model.

To achieve this, a database of CO<sub>2</sub> ice spectra with varying optical paths needs to be established using reference spectra [9], which are then downgraded to align with the spectral resolution of CRISM (6.55 nm). Following this, by introducing an additional parameter for contaminants (a ‘flat’ spectrum adjusted to correspond to

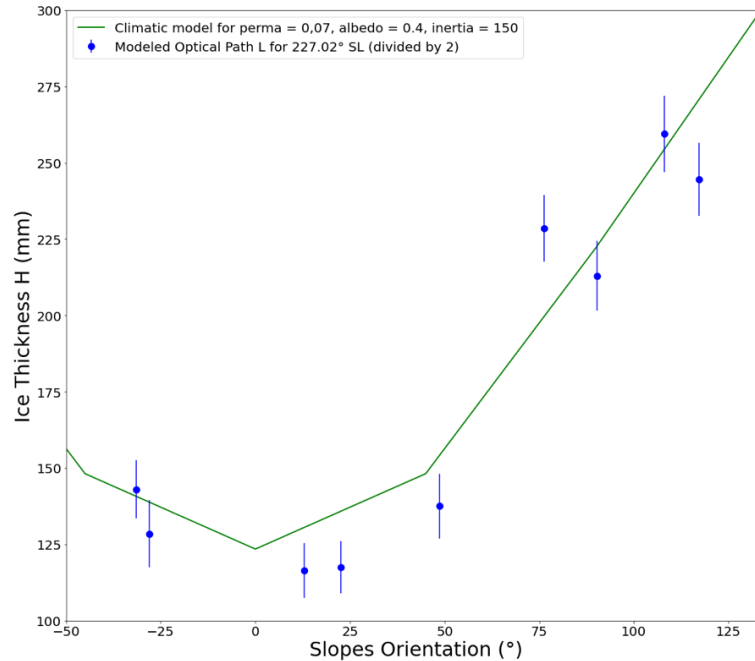


**Figure 1: CRISM observation of Sisyphi Cavi (68.46°S, 1.36°E) for Ls 227.02° (FRT00011935). Slopes azimuths varying from South-East to North (equator) facing are indicated.**

the data’s continuum), the database is compared to CRISM data through the minimization of quadratic deviations. From this fitting process, the optical path, percentage of pure CO<sub>2</sub> ice, and contaminant percentage are obtained. The optical path is then transformed into ice thickness by dividing it by an empirical factor. This factor should be representative of the geometrical path of light through the ice layer which depends notably on slope orientation, solar incidence angle and level of scattering by the atmospheric particles (it typically ranges between 2 and 3). This thickness is then compared to predicted ice thickness from a climatic model [10,11].

From these comparisons, first conclusions can be drawn: if the modeled ice thickness aligns with the trends and/or absolute values of the predictions from the climatic model, the observed ice is likely transparent or translucent. However, if the modeled thickness does not align with any trends or values predicted by the climatic model, it suggests that photons are unable to penetrate through the whole ice layer and are confined to “seeing” only the upper part of the ice layer, indicating that this upper part, or even the entire layer, is in granular state.

**First results:** Ice detections as a function of solar longitude obtained from various datasets [7] enables the retrieval of suitable climate model parameters for that location (Fig. 2) following the approach discussed in [6]. The climate model is then used to forecast the ice thickness across various slope orientations (Fig. 2).



**Figure 2 : Ice thicknesses as a function of slope azimuth.** Ice thickness derived from the CRISM observation assuming transparent ice (blue dots) are compared to predicted ice thickness by the climate model (green line). Used climate model parameters are indicated on top (“perma” refers to permafrost depth in meters, “albedo” to  $CO_2$  ice albedo and “inertia” to the upper regolith thermal inertia in standard unit “tiu”).

We compare in Fig. 2  $CO_2$  ice thicknesses derived from the CRISM observation of Fig. 1 to the thicknesses predicted from the climate model as a function of slope azimuth. The two datasets align well both in terms of their trend and the absolute values. Hence, this is consistent with the hypothesis that ice is transparent or translucent at this solar longitude ( $L_s 227.02^\circ$ ). We also retrieve the percentage of non-icy material in the pixel of typically 40-50%. This estimation is expected to include several effects: the presence of material at the surface that masks part of the ice (e.g., regolith grains deposited after geyser activity), the presence of dust in the atmosphere that scatter photons before they reach the ice, or the presence of contaminants within the ice that scatter some photons before they reach the ground below the ice.

**Conclusions:** This study reveals that the ice observed at  $L_s 227.02^\circ$  in Sisyphi Cavi, when and where some activity has been reported [12], exhibits a spectral signature consistent with it being in a translucent state. Additionally, analysis indicates contamination by dust and/or regolith particles, estimated at approximately 40-50%.

**Next steps:** In subsequent research, we plan to expand this methodology to include other solar longitudes

within the Sisyphi Cavi region. The next focus will be the analysis of an observation obtained significantly earlier (HRL00010475 at  $L_s 183.25^\circ$ ). Our objective is to assess whether ice transparency changes as a function of season and slope orientation, and then to look for correlation between ice state and activity timing or localization. We will then explore additional sites and regions exhibiting active gullies.

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