Polarized reflectance of flash-frozen ice particles.

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Introduction: In-situ and telescopic observations of icy moons during the last decades have improved our understanding of these bodies. One of the main features discovered is the production of pristine material at their surfaces by plumes detected on Enceladus[1, 2] and possibly on Europa [3]). In such dynamical environment, the ice particles could be produced by flash-freezing of aqueous solutions expulsed from the subsurface [4, and references therein].

At the University of Bern, the Setup for Production of Icy Planetary Analogues (SPIPA) [5] allows the production of flash-frozen particles by pulverization of liquid salty solutions on liquid nitrogen. The freezing of the particles is dominated by the Leidenfrost effect [6] which, due to the temperature difference between the liquid nitrogen and the aqueous solution, generates an outgassing of liquid nitrogen that makes droplets levitating above it. Therefore, the first seconds of crystallization are made at lower (and rapidly decreasing) temperature and induce a complex structure of particle, made of amorphous and crystalline phases.

The characterization of icy surfaces in total light intensity can be complemented by the analysis of the degree of linear polarization of the light scattered by atmosphereless bodies, remotely observed from the ground [7]. For many years now, ground-based polarimetric observations have provided a consequent dataset to finely characterize icy surfaces [8, 9] and therefore allow a better preparation for the upcoming space missions Europa Clipper (NASA) and JUICE (ESA).

The polarized reflectance is highly sensitive to the morphology of grains (e.g. size, shape, structure) as much as the chemistry (e.g. composition and mixture) [10]. The evolution of polarimetric properties of salty ice particles during warming-up, accompanied with the transition of the amorphous part into crystalline, gives insights on the morphology (mostly internal, but also external) of the grains, for the considered salt. To this extent we have measured, as preliminary experiments, the evolution of the degree of linear polarization of salty ices with temperature raising until the eutectic point of the solutions (NaCl and $MgSO_4$).

POLICES setup: The POLarimeter for ICE Samples has been developed at the University of Bern to measure, among others, the degree of linear polarization of icy samples [10] and its dependence to phase angle. The experiment is a goniometer with a fixed emergence angle. The incidence angle is defined by the position of the light source, fixed at the extremity of a rotating motorized arm. Light is either produced by LEDs at three different wavelengths (530, 625 and 810 nm), or in another configuration with a monochromator to select narrow spectral bandpasses. In both cases, depolarizers are used to ensure that the light incident on the sample is completely unpolarized, as the Sun light.

To permit repeatable measurements of icy samples, a hermetic box, painted in black to mitigate stray light, has been added to the setup in order to control the relative humidity in the atmosphere around the sample and prevent the formation of frost (Fig. 1A). As depicted in Fig. 1B, polarimetric phase curves of icy analogues can be measured with a phase angle ranging from 1.5° to 73° inside the box [10]. Here however, we worked with a fixed phase angle (arm position) to obtain a better time resolution of the evolution of salty-ice particles as their temperatures increases. Now that the kinetics of evolution are known, we will plan future measurements with variable phase angles.

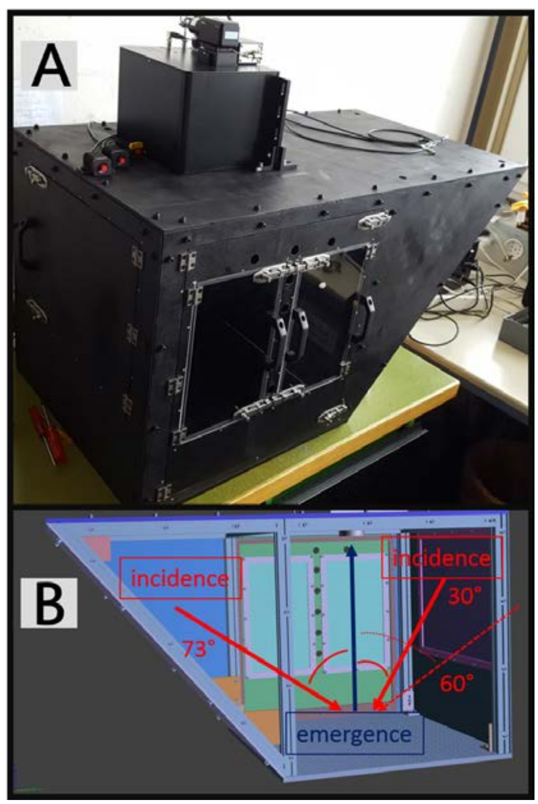

Figure 1: A) POLarimeter for ICE Samples (POLICES). B) 3D Back view with geometry of observation

Sample preparation and measurements: The degree of linear polarization is maximum at 90° of phase angle [7]. This particular configuration is not reachable with our setup, nevertheless, 60° of phase angle is already a good compromise to record the evolution of linear polarization. We prepared salty ices of spherical grains of 70±30 µm [5] from saturated aqueous solutions of respectively 30wt% of NaCl and 30wt% of $MgSO_4$.

The ice was then placed inside POLICES on a copper plate precooled with liquid nitrogen, and the Stokes coefficients, from which the degree of linear polarization is derived, was continuously measured during the slow warming-up of the sample up to the eutectic point. A Pt-100 sensor inside the ice sample allowed us to continuously measure the temperature of the ice, a few millimeter under the surface of the sample. The idea behind this experiment was to understand how the polarimetric properties of a flash-frozen sample would evolve during warming-up.

Figure 2 shows the evolution of the degree of linear polarization of the ices with temperature. The two different salty ices, prepared with different salts, are showing different evolutions of the degree of linear polarization. The analyses of such curves is still under progress. The pristine material is, as far as understood for now, a mixture of amorphous phase of water and salt, as much as a partially crystallized water ice, in hexagonal and potentially cubic phase [11]. The evolution with temperature corresponds to the reorganization of the sample, leading to a higher degree of crystallinity of both the ice and the salts. Through this process, the cubic ice initially produced would transition to hexagonal ice and the amorphous arrangement of water and salt become crystalline. As the water crystallizes, it expels the salt either outside of the particles, coating their surfaces or inside internal cracks within the particle.

The first steps of growth of these crystals (water ice and hydrated phases of salts) could be responsible for a minute fraction of Rayleigh scattering, associated to particles that are small in regard to the wavelength, and which generates an important increase of the degree of linear polarization. This mechanism is suspected to be responsible for the peak of polarization at 175 K for the $MgSO_4$, and centered around 190 K for NaCl seen on Fig. 2

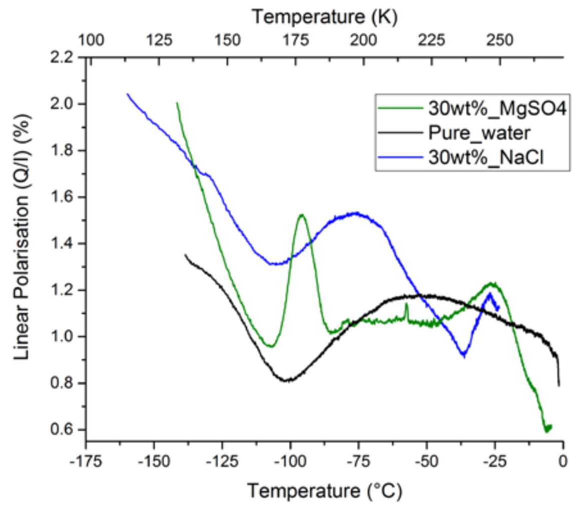

Figure 2: Evolution of the degree of linear polarization of salty ices with temperature.

Summary and perspectives: The measurements of the degree of linear polarization has shown its relevance regarding its sensitivity to the morphology at particle scale [10]. The new series of measurements proposed in this work could complete the analyses of such brines in total light intensity. For now only saturated brines have been tested, in order to decipher a potential systematic behavior. We intend to pursue this work with different amount of salts inside the initial brines, as much as other chemical species relevant for the study of icy moons. In addition to measurements at a fixed phase angle, phase curves should also be measured. Once validated, polarisation data will be distributed through the DACE and SSHADe platforms (https://dace.unige.ch/lossySearch/;https://www.sshade.eu/db/bypass).

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References:

[1] Nimmo, F., et al., (2007), *Nature 447*. [2] Postberg, F., et al., (2009), *Nature 459*. [3] Roth, L., et al, (2014), *Science 343*. [4] F. Nimmo, F., et al., (2014), in *Encyc. Solar System, Elsevier.* [5] Pommerol, A., et al., (2019), *Space Sci Rev 215*. [6] Feng, H., et al., (2018) *International Journal of Heat and Mass Transfer 127.* [7] Kolokolova, L., et al., (2015), *Cambridge University Press.* [8] Kiselev, N., et al., (2009), *Journal of Quantitative Spectroscopy and Radiative Transfer, 110*. [9] Rosenbush, V., et al., (2015), *Polarimetry of Stars and Planetary Systems, 340.* [10] Poch, O., et al., (2018), *Journal of Geophysical Research: Planets, 123.* [11] Uchida, T., et al, (2010), *Phys. Chem. Chem. Phys., 12.*