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Polarimetry of water ice particles providing insights on grain size and degree of sintering on icy planetary surfaces

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1. Context

The polarimetry of the light scattered by planetary surfaces is a powerful tool to complement observations performed in total light intensity, such as reflectance studies, providing additional constraints to interpret remote sensing observations of bodies in the Solar System and beyond [1]. For atmosphereless bodies, the unpolarized sunlight acquires its polarization when scattered by the first micrometer of their surfaces. The degree of polarization of the scattered light is particularly sensitive to the morphology (eg. size, shape, structure) and the chemistry (eg. composition, mixture) of the grains constituting the surface.

The fine characterization of the surface of icy bodies such as the Galilean moons (Europa, Ganymede and Callisto) is of major interest for future ESA (JUICE) and NASA (Europa Clipper) missions. Ground-based polarimetric observations of the icy satellites, conducted since many years [2, 3], provide a very precious dataset to prepare and complement the observations of these future missions. However, the interpretation of these polarimetric data is made difficult by the lack of good reference measurements, especially on surfaces made of ice. It is thus essential to build a database of polarimetric data on well-characterized samples of ice measured in the laboratory.

For this purpose, we have developed the POLarimeter for ICE Samples (POLICES) at the University of Bern, allowing measurement of the degree of polarization of the light scattered by surfaces in the visible range of wavelength (400 to 800 nm) and for 1.5° to 30° of phase angle. The setup uses a high precision photomultiplier tube coupled with two Photoelastics modulators (PEM) (Hinds Instruments) to measures the Q, U and V Stoke's parameters to describe the polarization of the scattered light.

2. Measurements and first results

We have prepared in the laboratory several surfaces made of pure water ice particles having well-controlled size and shape. We have measured the polarimetric phase curves of these surfaces and their temporal evolution, as the ice sinters. We noticed that the amplitude and the shape of the polarimetric phase curves are extremely dependent on the particles sizes and the degree of metamorphism of the ice.

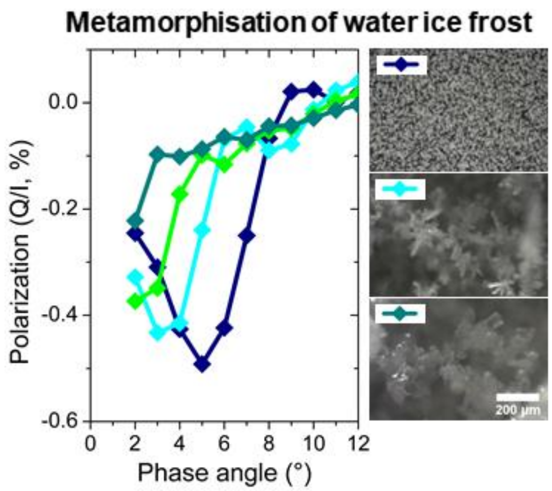

Figure 1: Polarimetric phase curves of an icy surface covered by frost growing and metamorphosing with time.

As an example, Figure 1 shows the phase curves measured during the nucleation, growth and metamorphism of water ice frost. Polarimetric phase curves of fresh frost nuclei exhibit strong oscillations typical of the Mie scattering by micrometric spherical particles (glory effect) [4]. As the spheres grow and the frost forms spikes and dendrites, the glory shifts to smaller phase angles. After few minutes, the frost evolves toward coarser irregular grains, leading to flatter phase curves and lower absolute degree of polarization.

We observed this significant change of the phase curve with time due to thermal sintering for all our ice samples. Sintering, which is driven by the reduction of the total surface energy of the system, acts more rapidly on smaller particles [6]. This phenomenon modifies the shape of particles by making bridges between them, modifying the way the light is scattered and therefore changing the polarization of the surface.

We have also measured well-controlled larger ice grains of 70±30 µm, characterized by shallower negative branch of polarization than fresh frost nuclei which do not exceed 10 µm large (Fig.2).

Figure 2 shows a comparison of some of our laboratory measurements with average disk-integrated polarimetric phase curves of icy satellites. These data suggest that the surface of Europa is covered by relatively coarser grains (~40-400 µm) than those of the surfaces of Enceladus, Rhea or the trailing hemisphere of Iapetus. These surfaces are more consistent with finer frost. We note that these conclusions, obtained from polarimetric data in the visible domain, are in line with those obtained from mid-infrared spectroscopy [6, 7].

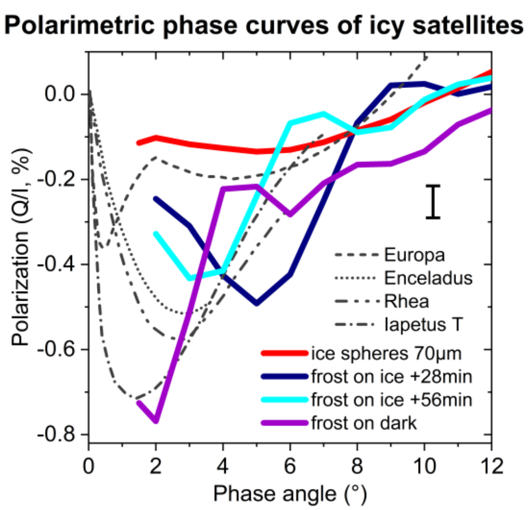

Figure 2: Comparison of our laboratory measurements [5] with disk-integrated polarimetric observations of icy satellites [3]

3. Summary and Perspectives

These measurements demonstrate the high sensitivity of polarization to the grain size and degree of sintering of ice particles. Therefore, polarimetry could be used to detect hints of ongoing processes on icy planetary surfaces, such as cryovolcanism or sputtering, producing coarse (via warming) or fine (fresh) ice grains. These first results open the way to further measurements with ice particles containing chemical impurities. We foresee to extend the measurements to icy mixtures consisting of water ice and colored chemical compound, such as sulphur, in order to investigate their polarimetric signal and constrain their possible identification by ground-based polarimetry observations of Europa's surface. The presence of salts could also influence the polarization of the light by modifying the morphology of the ice grains as well as its color.

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