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Photometric properties of micrometer-sized ice particles

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Abstract

We have measured the bidirectional visible reflectance of water-ice particles with mean particle radii of 1.5 µm over a wide range of emission and incidence angles. The results show a highly backscattering behaviour for fresh samples, contrasting with natural terrestrial snow and frost and showing similarities with the photometry of the surfaces of Enceladus and Europa. A significant temporal evolution towards more forward scattering phase functions is observed within some tens of hours, probably resulting from sintering processes.

1. Introduction

The understanding of how solar light interacts with icy surfaces in the outer solar system is crucial for the interpretation of optical remote sensing data. Laboratory experiments on well-characterized analogues provide an opportunity to directly compare measurements with observations and to test and improve numerical models.

Working with snow and other terrestrial natural forms of ice is a convenient starting point but is not sufficient for studies of other Solar System objects. We have measured here the bidirectional reflectance of surfaces consisting of spherical micrometer-sized water ice particles previously described by [2]. This artificial material shares a number of physical properties with the surfaces of icy satellites.

2. Methods

The photometric measurements were conducted with the PHIRE-2 radio goniometer [4] operated in a laboratory freezer at -35°C, ambient pressure and a relative humidity of 48%. The instrument consists of two mobile arms, one holding a collimated light source, the other a silicon photovoltaic detector to obtain different illumination and observation geometries. The minimum phase angle measured is 5°. Maximum angles are 60° for incidence and 70° for emission, respectively. Measurements were obtained at wavelengths: 450, 550, 650, 750, 905 and 1064nm. Relative measurement uncertainties are in a range of 0.5 to 1%.

The sample material was produced by dispersing liquid water with an inhalator directly into liquid nitrogen. This was performed in a custom-made Dewar vessel with an extraction valve beneath the liquid nitrogen reservoir.

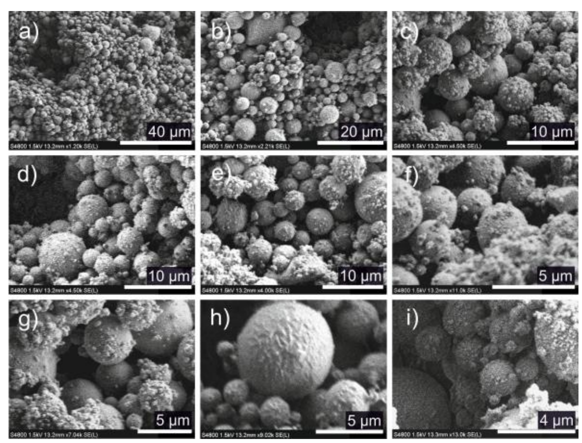

Figure 1: Scanning electron microscope images of the micrometer-sized water ice particles obtained with the cryogenic SEM of the University of Kiel.

The microscopic structure and particle size were investigated with a cryogenic cooled scanning electron microscope (SEM) at the University of Kiel (Fig. 1). The micrometer-sized water ice particles are of spherical shape with some finer frost formed by condensation of atmospheric water vapor on the outermost layer. The typical particle radius was derived from the mean of the logarithm of the measured particle radii as r= 1.47 +0.96 – 0.58 µm.

The measured reflectance curves were fitted using the newest version of the Hapke bidirectional reflectance model [3], which takes into account anisotropic multiple scattering. The resulting parameter sets can be used to reproduce our data, interpolate the measured values to other geometries or calculate integral quantities.

3. Results

Laboratory experiments were performed on three identically produced samples. The longest measurement lasted 41 hours. The individual samples show significant differences of up to 10% in reflectance value in their initial state. This probably originates from agglomerate formation during sample preparation. The fresh micrometer-sized ice particles show a dominant backscattering behaviour and an absence of forward scattering peak contrary to all types of terrestrial snow.

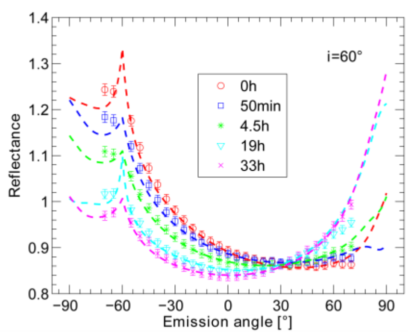

Figure 2: Long term evolution of the bidirectional reflectance of µm-sized ice, showing a decrease of reflectance at low phase angles and an increase at high phase angles. Incidence=60°.

A substantial temporal evolution of the photometric properties of all samples was observed (Fig. 2). The backscattering peak is continuously decreasing with time while the forward scattered fraction increases. Sintering processes, in which optical bonds between single particles are created, is the most plausible explanation for this observation.

The comparison of our measurements with the photometric properties of the surfaces of Europa and Enceladus [1,5], shows that a much better agreement is obtained with micrometer-sized ice particles than with terrestrial snow. This observation provides interesting insights into the texture of ice at the surface of these two icy satellites.

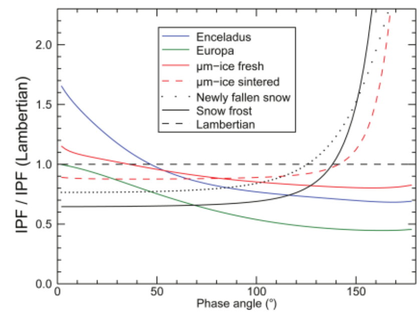

Figure 3: Normalized disk integrated phase functions plotted versus phase angle for Enceladus [5], Europa [1], µm-sized ice and terrestrial snows [1]. All curves are normalized to the integral phase function of an ideal lambertian surface.

4. Summary and Conclusions

We have performed bidirectional reflectance measurements on surfaces composed of pure micrometer-sized water ice. The photometry of the fresh material shows interesting similarities with the surfaces of icy satellites and radical differences to terrestrial snow. A steady evolution with time of the photometric behavior was observed, probably resulting from sintering processes.

Acknowledgements

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