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Low phase angle photometry of ice in the laboratory and implications for the surface of icy satellites

B. Jost (1), A. Pommerol (1), O. Poch (2), B. Gundlach (3), N. Thomas (1)

(1) Physikalisches Institut, University of Bern, Switzerland (bernhard.jost@space.unibe.ch), (2) Center for Space and Habitability, University of Bern, Switzerland, (3) Institut für Geophysik und extraterrestrische Physik, Technische Universität Braunschweig, Germany

Abstract

We have measured the bidirectional reflectance of micrometer-sized water ice particles in the visible spectral range over a wide range of emission and incidence geometries, including the exact opposition. The cm-size sample surfaces were prepared with different methods. We were able to detect a diffraction signal on the fresh sample material, which directly provides us with information about the particle size of the scatterers.

1. Introduction

The knowledge about the amplitude and shape of the so-called "opposition surge" –a nonlinear increase in brightness towards low phase angles– is a potentially very rich source of information on the textural properties (particle size, shape, porosity) of the surface materials. A good understanding of this phenomenon for ice surfaces is particularly crucial at a time where new missions toward the moons of Jupiter are planed and instruments in the design phase.

We have upgraded our existing PHIRE-2 gonio-radiometer to allow measurements of the reflectance at very low phase angle and study the opposition effect in detail. We have also updated our setup to produce spherical ice particles with a mean diameter of 4 to 8 µm in a sufficient amount to be measured on PHIRE-2.

2. Methods

All photometric measurements were performed with the PHIRE-2 gonio-radiometer [1] operated in a laboratory freezer at -35°C and ambient pressure. The system has two mobile arms, holding a collimated light source and a silicon photovoltaic detector to vary the illumination and observation direction. Compared to our previous measurement campaigns [2] it is now equipped with a beamsplitter system which allows is to acquire data in the exact opposition configuration, when the directions of incidence and emission are parallel [3]. The minimal angular resolution of the system is 0.5° and the possible wavelength range: 450-1064 nm.

We have developed a novel production method to create spherical ice particles with diameters in the range of 4-8 µm. Water is nebulized with an ultrasonic device and conducted into a small freezer with a liquid nitrogen cooling system. The produced ice was used to prepare three samples with different preparation methods (Fig. 1) in order to analyze the effects of macroscopic roughness and porosity.

We have measured the evolution of each individual samples for durations between 7 h and 23 h to investigate to photometric effects of the metamorphism of the ice.

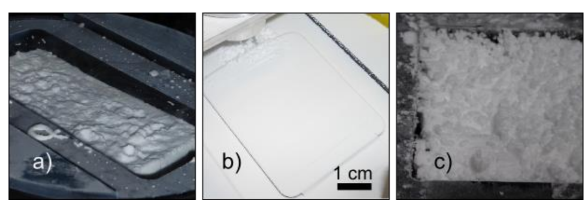

Figure 1: Pictures of ice samples prepared with three different surface preparation methods, (a, Method #1) mixing with liquid nitrogen, (b, Method #2) spraying on a plate, (c, Method #3) preparation with a spatula

3. Results

Sintering processes (see [2]), where optical bonds between single particles are created over time, are dominating the temporal evolution of the photometric properties of our samples. The amount of backscattering is continuously decreasing with time while the forward scattering fraction is less affected by sintering but shows a high dependence on the initial surface roughness.

The height of the non-linear opposition peak is decreasing with time (Fig. 2a). Its relative contribution to the total amplitude is decreasing from 8.5% to 3.5% within 6 h. The maximum amplitude decreases exponentially with time for all surface types, but with different initial values and decreasing rates (Fig. 2b).

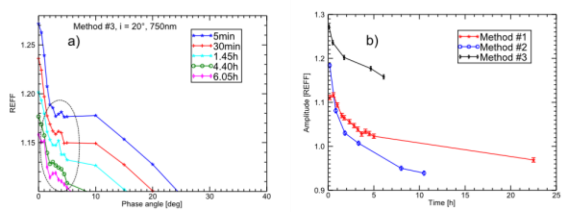

Figure 2: Temporal brightness evolution around the opposition geometry and diffraction peaks (indicated by dashed circle) for Method #3 (a); evolution of the maximum amplitude with time at i=e=0° for different preparations (b).

We observe on both sides of the opposition peak, separated by about 4°, signals that we interpret as diffraction peaks. This hypothesis was confirmed by the analysis of the wavelength-dependence of these features. From the analysis of the angular separation α (°) of the first order diffraction peak [4] one can directly calculate the particle diameter *d* of the individual scatterers using the Mie theory assuming perfectly spherical particles (see Eq. 1).

$$d = \frac{\lambda}{\alpha} \cdot \frac{180}{\pi} \qquad (1)$$

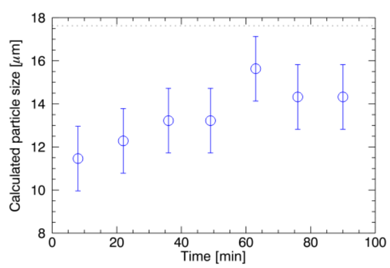

Figure 3: Deduced diameter of the individual scatterers calculated from the angular separation of the diffraction peak (see Eq. 1) as a function of time

Within the first 90 min we observe an angular shift of the peak by about 1° which corresponds to a grain size increase from 11.5 µm to 14 µm.

4. Summary and Conclusions

We have performed low phase angle photometry on surfaces composed of µm-sized water ice particles having different surface textures. We observed systematic changes of the photometric properties with time such as a decrease of the opposition peak, attributed to the sintering processes at 238 K. We have found that the brightness at low phase geometry is increased by about 10% by the opposition effect in the case of pristine sample material.

Additionally we propose a novel method to invert particle size directly from low phase angle reflectance measurements, using the angular location of the first order diffraction peak. This method is working in the case of narrow particle size distributions and spherical particles, which are probably present on the surfaces of icy moons, such as Enceladus and Europa.

Acknowledgements

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References

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