Spectro-photometric studies of cometary analogues in the LOSSy Laboratory at the University of Bern

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Introduction

Many observations of Solar System surfaces rely on the analysis of the solar light scattered by the materials that compose their uppermost layers. A good understanding of this process, through physical modeling and/or laboratory experiments, is thus crucial for detailed analyses of remote-sensing datasets.

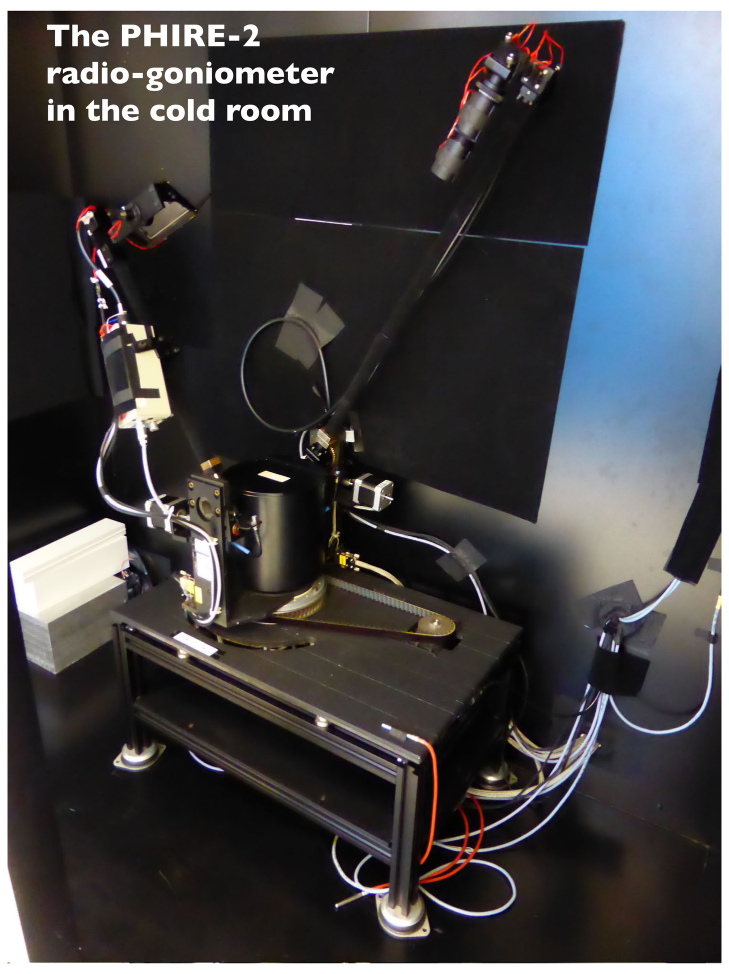
We have set up the LOSSy laboratory (Laboratory for Outflow Studies of Sublimating Materials) to study the spectro-photometric properties of various analogs of planetary object surfaces, with a special emphasis on icy samples and their evolution under simulated space conditions. This laboratory is currently equipped with two facilities: the PHIRE-2 radio-goniometer, designed to measure the bidirectional visible reflectance of samples under a wide range of geometries and the SCITEAS simulation chamber, designed to follow the evolution of icy samples subliming under low temperature and low pressure conditions by means of VIS-NIR hyperspectral imaging.

We report here on the results of different experimental studies undertaken in the LOSSy laboratory, all related to the spectro-photometric characterization of materials produced and processed as plausible analogues for comets nucleus material. Independent and detailed physical and chemical characterization of these analog samples is crucial for the usefulness of the photometric data.

Our main objective with these experiments is to produce catalogs of laboratory data, which can be used to enhance our interpretation of future remote and in-situ optical observations of comet nuclei, in particular those of instruments on board Rosetta and Philae.

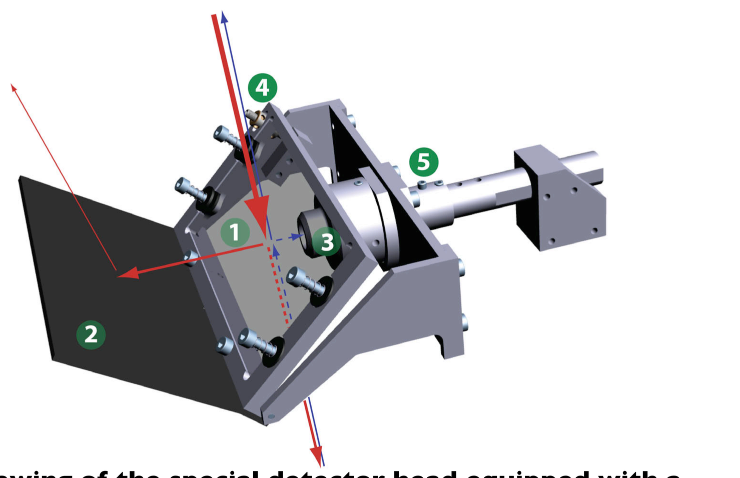
Instrumentation

Measurements presented here were all acquired in the LaPIA (Laboratory for Photometry of Icy Analogs) at the University of Bern [1]. LaPIA is part of the LOSSy (Laboratory for Outflow Studies of Sublimating Materials) facility. Two instruments were used: the PHIRE-2 (PHysikalisches Institut Radiometry Experiment, v.2) and the SCITEAS (Simulation Chamber for Imaging the Temporal Evolution of Analog Samples)

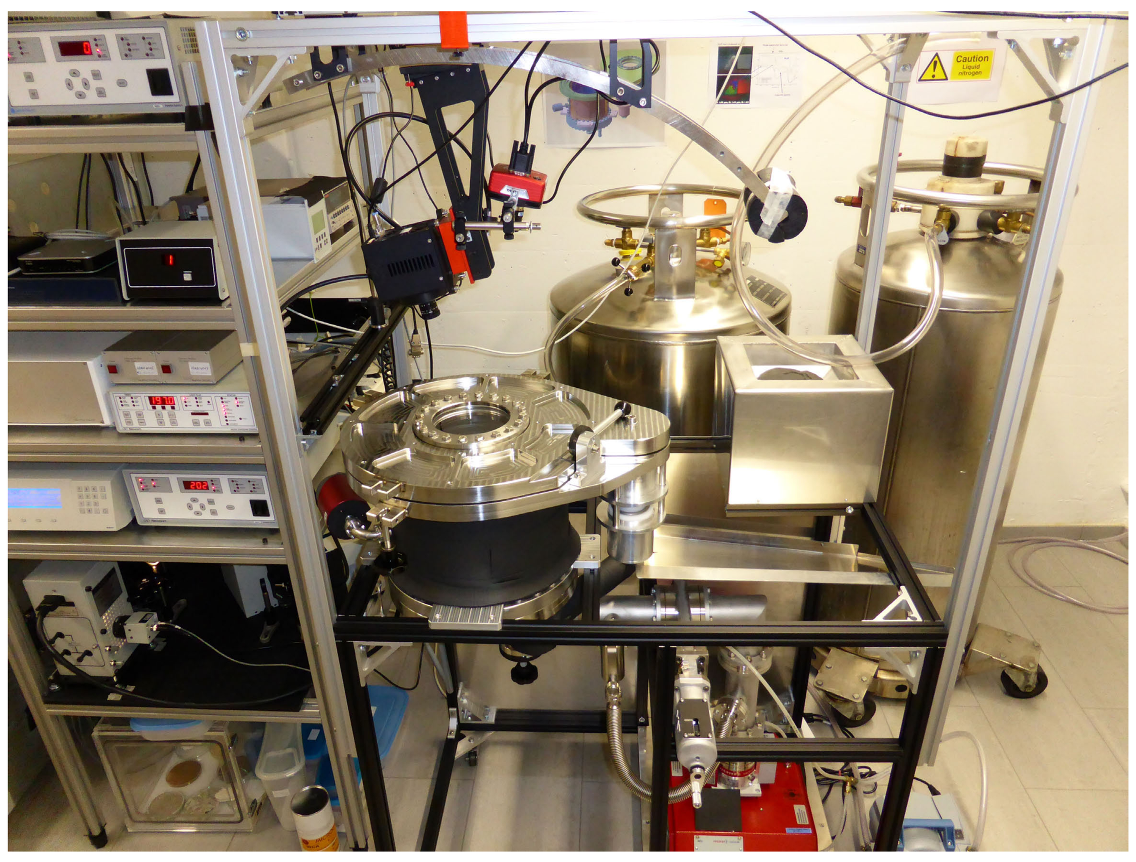


The PHIRE-2 instrument is a highly accurate and fully automated radio-goniometer that is operated at -30°C in a cold room to acquire measurements with icy samples [1]. It is used to measure the bidirectional reflectance with a high accuracy over wide ranges of incidence, emission and phase angles. Reflectance values were measured inside six discrete bandpasses between 400 and 1100nm.

This instrument has been in use for many years but we have recently significantly upgraded it to permit measurements of the bidirectional reflectance at low phase angle, including the exact opposition (g=0°).



CAD drawing of the special detector head equipped with a beamsplitter used to acquire measurements at low phase angles



The SCITEAS simulation chamber is designed to accommodate the same sample holders as the ones used with the PHIRE-2. Samples are thus easily interchangeable between both instruments.

The closing system of the chamber was optimized for quick and easy sample insertion/removal.

The chamber is cooled by liquid N_2 and evacuated using membrane and turbo-molecular pumps.

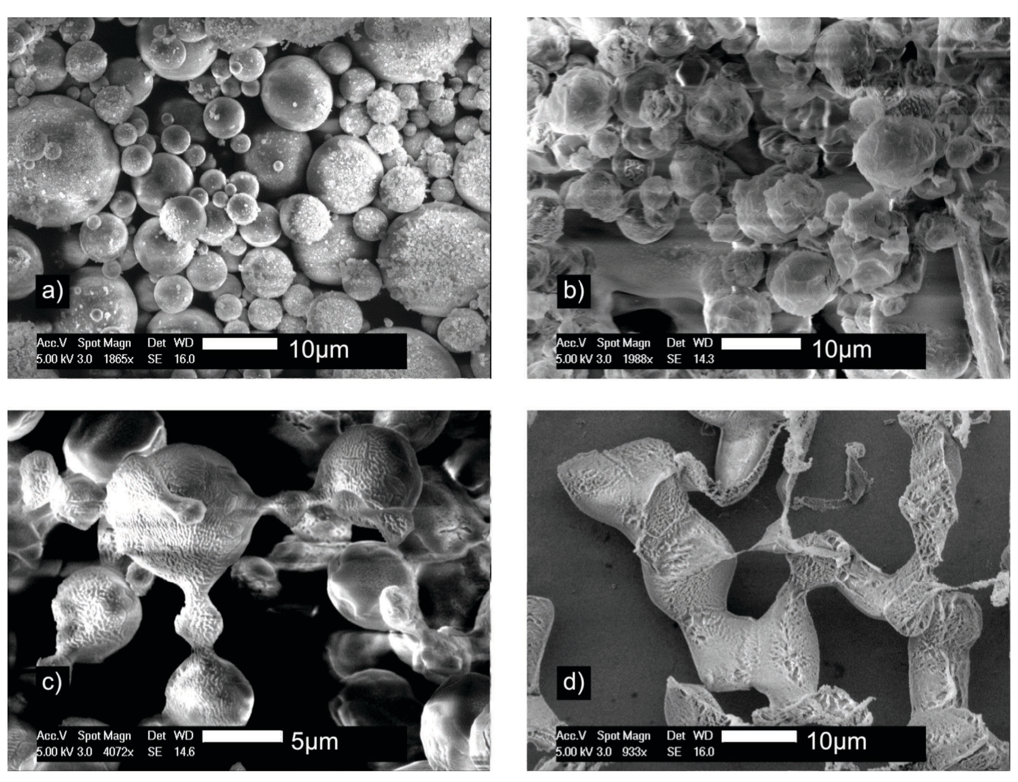
An original imaging system was developed to acquire hyperspectral images of the sample through a large quartz window over the spectral range: 0.4-2.5µm.

Various feedthroughs on the bottom flange of the chamber permit complementary in-situ investigations (temperature) and interactions with the sample.

Samples

Spraying fine droplets of liquid water into liquid nitrogen has always been a popular technique to produce the fine-grained water ice needed for comets nucleus analogues [2,3]. Following the successful use of the setup built at TU Braunschweig for initial experiments [4], we have built our own setup based upon the same technique but optimized for higher production rates in order to produce rapidly the thick layers of ice needed for our experiments.

The ice production machine, SPIPA (Setup for Production of Icy Planetary Analogs), was designed to be transportable (in the trunk of a car) so that the machine can be easily brought to the location where the sample will be characterized. In addition to the LAPIA laboratory, we have used the SPIPA setup at CSEM in Neuchâtel where a cryo-SEM (Scanning Electron Microscope) could be used to image the particles of ice



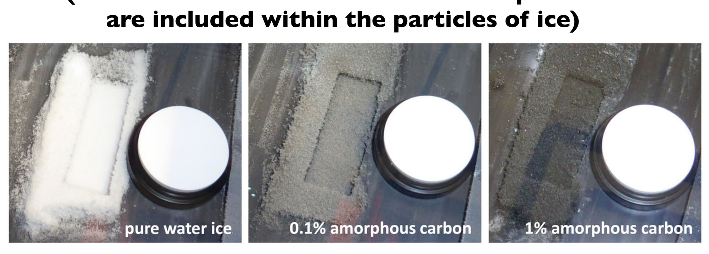
The cryo-SEM picture on the left show the shape of the individual particles of ice. Initially perfectly spherical (a), these particles rapidly sinter (c, after one hour; d, after 12 hours). This sintering is certainly the reason for the evolution of the photometric behaviour of the sample, as previously hypothesized in [4].

Image b) shows particles which were stirred into liquid nitrogen, mimicking the procedure we use to mix the ice, mineral and organics fractions to produce comets analogs. The stirring in LN2 has a noticeable effect on the shape of the grains, which show facets.

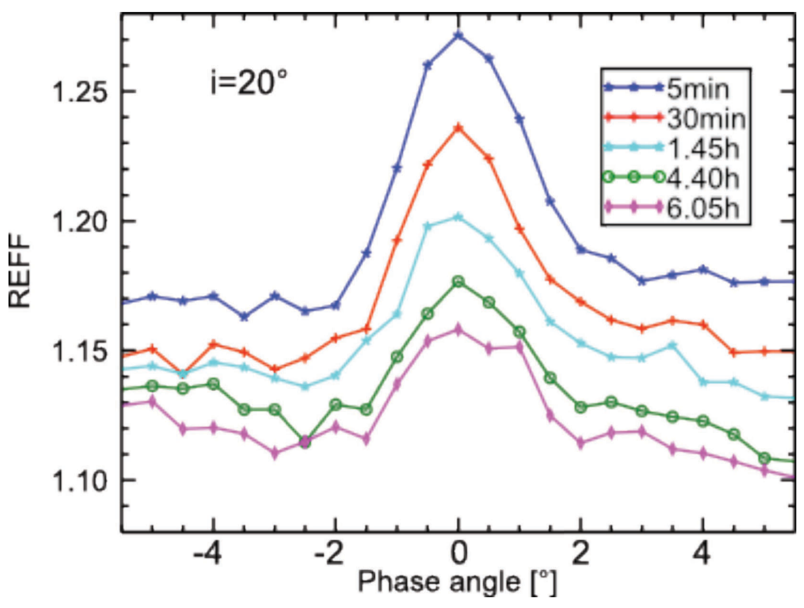
We have used these images to calculate the volumetric size distribution of the initial material produced by the SPIPA setup. The average diameter is about 10µm.

In addition to the ice produced in the SPIPA setup, we have used an ultrasonic nebulizer to produce ice particles with a larger particle size (70µm average diameter).
The next step in the production of comets analogs is the mixing of the different phases, which we can perform via different protocols (ultrasonic dispersion, liquid nitrogen, dry vortexing).

Different intra-mixtures of 70µm-ice and amorphous carbon (i.e. in this case the nm-sized carbon particles are included within the particles of ice)



VIS bidirectional reflectance



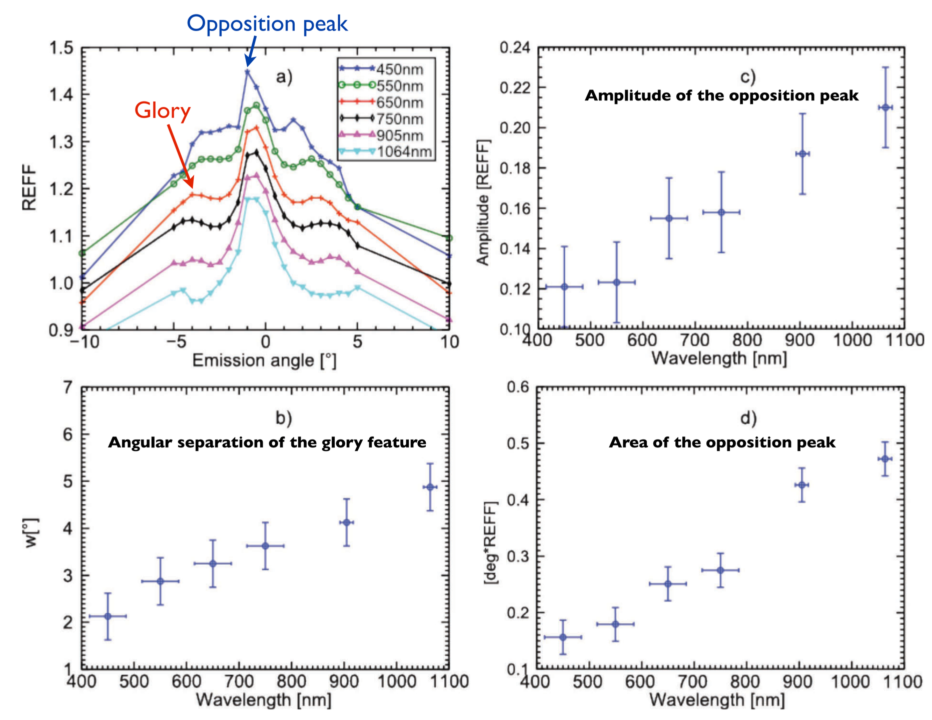
The figure on the left shows the temporal evolution of the photometry of a sample of pure water ice produced with the SPIPA setup (average particle diameter=10µm). The sample was placed in the PHIRE-2 freezer where the temperature is kept constant at 240K and the relative humidity stays around 50%.

Here, we have zoomed on the opposition region. The intensity of the opposition peak is observed to continuously decrease with time. This evolution of the photometry at low phase angle, as well as the evolution at high phase angle previously documented by [4] (increase with time of the fwd/bwd scattering ratio), is caused by the sintering of the particles as shown in the SEM images.

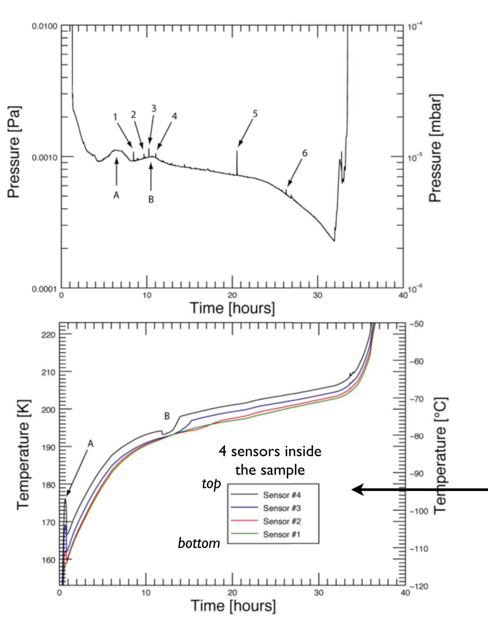
Observations at multiple wavelength (right) show very interesting spectral effects. Because the rapid evolution of the ice sample makes multispectral measurements difficult, we have completed our data with glass spheres of the same diameter.

The data on the right clearly show nearly linear relationships between the intensity and width of the opposition peak and the wavelength. This indicates the strong contribution of Coherent Backscattering to the Opposition Effect (CBOE mechanism, [5]).

We also see evidence for «glory»: the secondary maxima at phase angle of 3 to 5° on both sides of the opposition peak. This is an effect generally observed over clouds on Earth and on Venus [6,7] as it requires very spherical particles. It seems that it is also observable on solid surfaces. This could have interesting implications for the determination of particle size on the icy surfaces of outer solar system satellites.



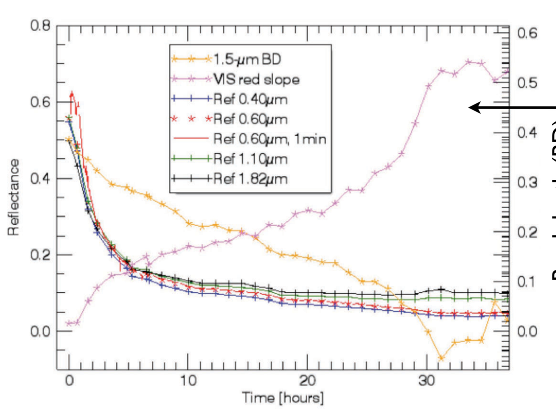
Sublimation experiments



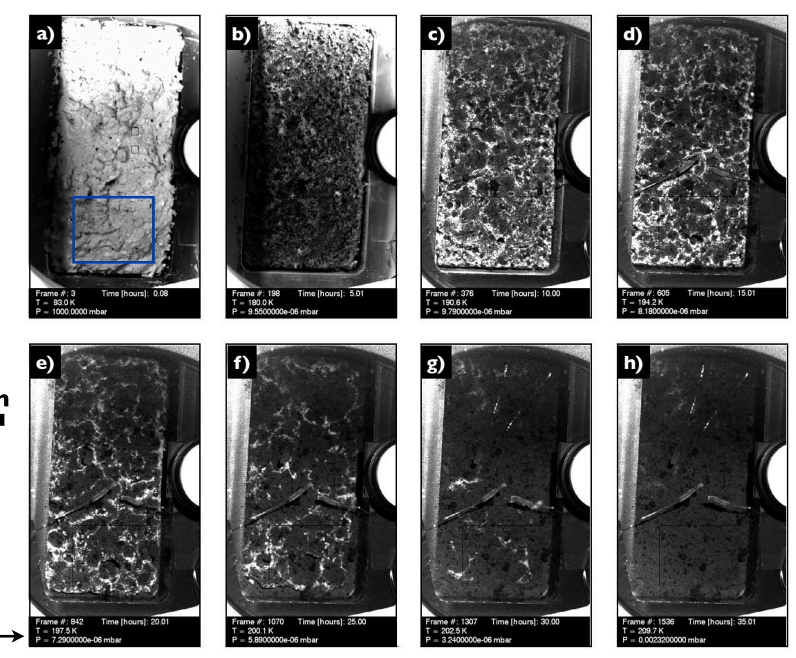
The figures on the left and below show some results of our first sublimation experiment conducted in the SCITEAS sublimation chamber. Fine-grained ice was intimately mixed with 5 wt.% basalt powder and 1 wt.% carbon black in LN2 to produce a very simple comet analog, 2cm thick. This sample was then exposed to vacuum at low temperature and left to sublimate for 40 hours. Pictures and VIS-NIR hyperspectral cubes were regularly acquired.

The general temporal evolution of the photometry of the sample is dominated by the formation of a desiccated upper mantle of mineral and organic matter at the surface of the sample. The morphology of the surface is dominated by the extension and interactions of circular depression exposing ice on their rims.

Conditions of pressure and temperature during the sublimation experiment



Temporal evolution of some spectro-photometric criteria averaged over the large ROI shown in blue on image a) (right) 1.5-µm BD is the strength of the H_2O absorption band Ref is the reflectance factor



8 frames extracted from a video assembled from pictures of the surface taken every minute for 36 hours.

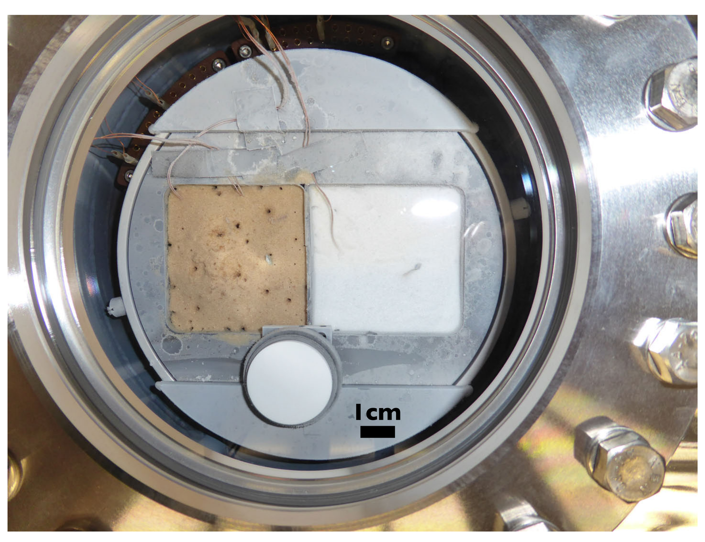


Figure on the left shows an example of «intra-mixture» between water ice and tholins. The organic phase, made of C,H,N-molecules and macromolecules (tholins produced at LATMOS*) has been thoroughly mixed with distilled water using ultrasound. Then the obtained suspension of tholins in water has been nebulized into liquid nitrogen to produce fine-grained ice composed of spherical particles of 67±31 µm in diameter and containing 0.1 wt% of organics. The ice was left to sublime in the SCITEAS setup, under vacuum (10^{-5} mbar) and at low temperature (-70°C) for 45 hours, simulating the evolution of the surface of a comet nucleus approaching the Sun.

As the water sublimes, the surface of the sample becomes covered with a mantle of dry organics, having a porous structure (right). Fragments of this mantle are episodically ejected during the simulation, presumably because of the accumulation of gas produced by the sublimation of water ice below the mantle. After such ejection events, fresh unaltered icy particles are exposed to the surface and then gradually sublime. The porous organic mantle reduces the sublimation of the ice by a factor of 4 compared to a similar sample composed of pure water ice particles.

References

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http://space.unibe.ch/pig/science/lossy