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Laboratory analogues for the icy moons of Jupiter – The added value of a time-of-flight mass spectrometer

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Abstract

The surfaces of Jupiter's icy moons are continually irradiated by charged particles from the Jovian plasma environment. This irradiation triggers chemical reactions in the surface ice and also acts as an atmospheric release process. Remote observations, theoretical modelling, and laboratory experiments must be combined to understand this plasma-ice interaction. This presentation takes a closer look at the latter: we summarize our previous experimental findings and present our ongoing work on the chemistry of irradiated water ice samples relevant for icy moons and other icy objects in the solar system.

1. Introduction

The University of Bern is developing the neutral gas mass spectrometer for ESA's Jupiter Icy moons Explorer (JUICE [5]), planned to reach the Jupiter system in 2029. We therefore strive to fill gaps of knowledge about the basic physics of the surfaces and atmospheres of Jupiter's icy moons before the arrival of JUICE. We combine the available facilities for developing and calibrating mass spectrometers and ion/electron spectrometers [7] with the sample preparation techniques and diagnostics of the Planetary Imaging Group [9, 6].

2. Previous laboratory results

Over the last years, we have experimented with a wide variety of water ice samples in vacuum conditions, ranging from dense ice films (100 nm) on microbalances to thick (1 cm) and porous ice regolith (see Fig. 1). We subjected these ice samples to electron and ion irradiation and quantified the sputtering yields and other loss processes. Among other things, we derived the first experimental sputtering yields for sulphur ions irradiating water ice [3] and we extended the energy range of known sputtering yields for electrons [4].

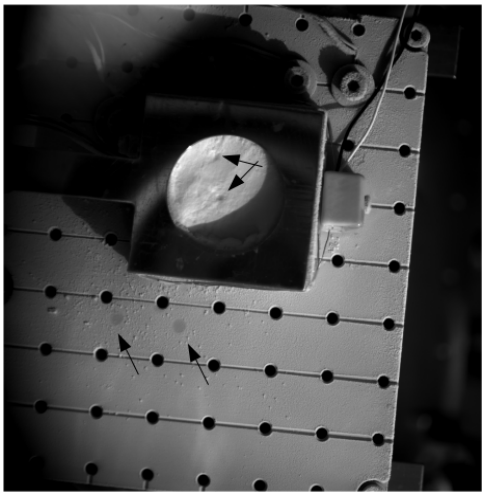

Figure 1: Photograph of fine-grained water ice sample [4]. Arrows indicate places where the electron beam irradiated the sample and the water frost around it.

3. Ongoing work

We have shifted our attention to studying the chemical and physical alterations in ice samples upon irradiation with electrons and ions. We monitor these processes with spectral cameras in the visible and near-infrared wavelength range and with a dedicated new time-of-flight mass spectrometer (see Fig. 2). The physical and optical properties of these macroscopic ice samples make them realistic analogues for planetary surfaces (see Figure 3). The effect of chemical impurities in the water ice, such as NaCl, can also be investigated.

A recent result with applications to icy moons

Figure 2: Photograph of the new reflectron-time-of-flight mass spectrometer under assembly.

and comets concerns the radiolysis of H_2O ice upon electron irradiation: measurements with our old quadrupole mass spectrometer indicated that the freshly produced H_2 leaves the porous water ice sample immediately whereas the O_2 escape slowly increases before reaching a steady-state ratio of 1:2 compared to H_2 (see time series in Fig. 3). These measurements imply that irradiation of thick regolith ice results in the formation of an irradiated water ice layer with an O_2/H_2O ratio of 0.01–0.02. This is the same order of magnitude as the O_2/H_2 ratio inferred from surface reflectance spectra for Ganymede, Europa, and Callisto [2, 8] as well as from ROSINA measurements for 67P/Churyumov-Gerasimenko [1]. However, the shortcomings of the previous mass spectrometer are obvious in Fig. 3: the time resolution is too slow to study rapid changes and the mass resolution is insufficient to discriminate, e.g., between heavy O_2 isotopes and H_2O_2.

In this presentation, we will show our first results obtained with the new custom-built time-of-flight mass spectrometer to further investigate the radiolysis of water ice and the resulting abundance of O_2 and other radiolysis products inside and outside the porous water ice.

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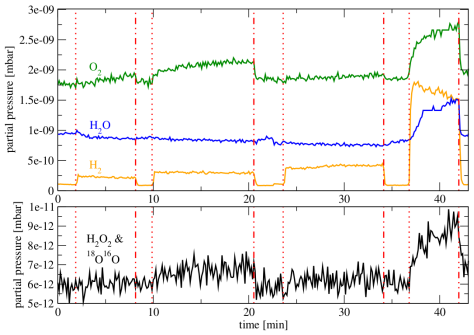

Figure 3: Time series of ejected molecules from pure water ice upon electron irradiation. [4].

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