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# Modelling of NIM/PEP/JUICE measurements of Callisto's ice-sputtered exosphere

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## Abstract

The JUpiter ICy moons Explorer (JUICE) mission [1], which is currently in implementation by the European Space Agency (ESA), is intended for the detailed investigation of the giant gaseous planet Jupiter and its three largest moons, Ganymede, Callisto and Europa. The Particle Environment Package (PEP), part of JUICE's science payload, contains 6 sensors for comprehensive in situ measurements of electrons, ions and neutrals found in the Galilean moons' vicinity [2]. One of the suite's sensors, the Neutral and Ion Mass spectrometer (NIM), will measure the neutral and ion composition of the exospheres of the three satellites during flybys and in orbit.

Whereas Callisto's surface has been mapped as early as in 1980 by the two Voyager missions, still little is known today about the nature of its atmosphere, due to its tenuousness also called exosphere. It is assumed that Callisto is not fully differentiated and that its surface composition consists of about half ice and half mineral contents [3]. Thus, composition measurements at Callisto offer the unique opportunity to measure the full spectrum of building blocks of the Jupiter system.

We present here modelled density profiles of Callisto's ice-sputtered exosphere based on new laboratory measurements of ice sputtering. The sputtering measurements were conducted in our laboratory on a sample of dense and porous salty ice, specifically manufactured to simulate sputtering of the Galilean moons' icy surfaces.

## 1. JUICE – PEP / NIM

The Neutral Ion Mass Spectrometer (NIM), one of the instruments of the Particle Environment Package (PEP), will conduct the first-ever direct sampling of the exospheres of Europa, Ganymede, and Callisto. NIM is capable of detecting exospheric neutral gas and thermal plasma at the Galilean moons with very high mass resolution and unprecedented sensitivity. The mass resolution is $M/\Delta M > 1100$ in the mass range 1–1000 amu and NIM's energy range is ≤ 5e V for neutrals and <10 eV for ions. The detection level for neutral gas is $1\cdot10^{-16}$ mbar for a 5-second accumulation time, which corresponds to a particle density of about 1 $cm^{-3}$. With such a detection limit, NIM will be capable of recording mass spectra during the satellites' flybys starting at $10^5$ km altitude. NIM will thus during a single flyby record more than 1000 mass spectra with varying integration time, covering several hours of measurements.

## 2. Callisto's ice-surface composition

The surface of Callisto consists to about 50 % of an icy component. For this surface we implement two different composition models that find analogues in the initial gas phase conditions of the solar nebula: One composition represents the oxidizing state and the other represents the reducing states of the gas [4, 5]. The density curves we simulate incorporate first experimental results from a facility at the University of Bern used to simulate ion sputtering on the surface of the icy moons of Jupiter [6]. These experiments provide us with new, improved sputtering yields, which we can use to simulate ab initio density curves.

## 3. Monte Carlo simulation of Callisto's ice-sputtered exosphere

We present density profiles for all species present on Callisto's icy surface, as computed by our Monte-Carlo Model. The Monte-Carlo model used is an updated version of the model first presented in [7].

In this model, the trajectory of each individual particle is simulated from its point of origin until it either overcomes the parent body's gravitational attraction or changes its nature. As source processes we consider: 1) surface sublimation, 2) sputtering, and 3) photon-stimulated desorption, with emphasis on ice-sputtering. Particles are lost by one of the following sink mechanisms: 1) escape, 2) ionization, 3) fragmentation, or 4) surface adsorption. We ran $10^5$ trajectories for each species.

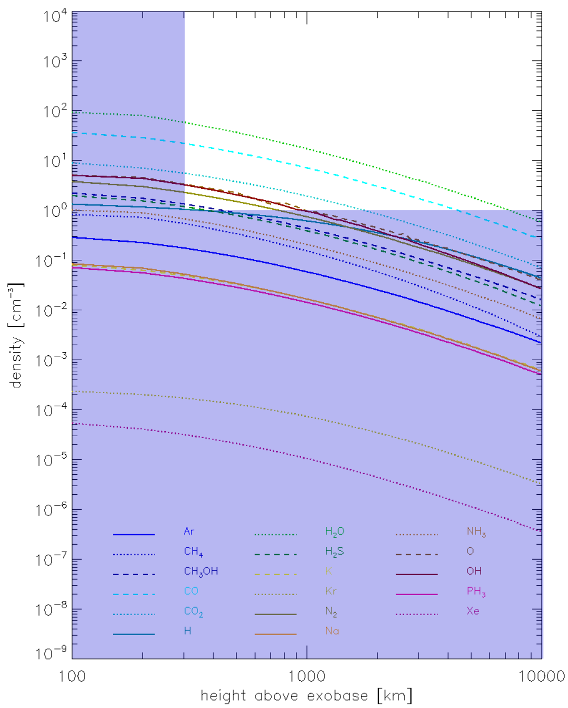


Figure 1: Example density profiles for the major constituents sputtered from the icy surface. Shown in blue is the minimal altitude reached by JUICE and NIM's nominal background.

## 4. NIM Simulations

In addition to the simulated density profiles, we also present mass spectra as we expect NIM to measure during the Callisto flybys based on the newest JUICE trajectory. Our mass spectra plots show that as far as $10^5$ km above the surface, NIM is capable of detecting a signal from the most abundant species above its background level. The closer JUICE approaches the moon, the more species, and, notably, species released from the surface through different release processes will be detected by NIM. At closest approach, a single mass spectrum recorded during a time interval of 5s will exhibit mass peaks for almost all species released thermally and most species released by ion sputtering from the icy surface.

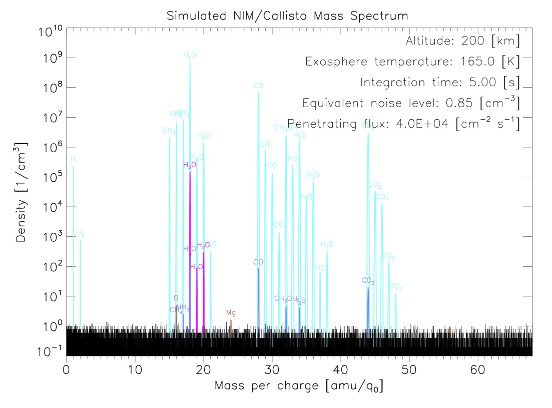


Figure 2: Example mass spectrum as expected to be recorded by NIM during closest approach (200 km) of Callisto. Cyan denotes sublimated, blue denotes ice-sputtered, brown denotes mineral-sputtered, and magenta denotes photo-desorbed species.

## 4. Discussion and Conclusion

The density profiles of the ice sputtered species start at rather low values (compared to their sublimated counterparts), but have smaller scale heights, due to their higher temperatures and eject velocities. In fact, the most abundant species are detectable to NIM starting at Callisto's Hill radius (~$10^5$ km). Since the JUICE flybys are as low as 200 km above Callisto's surface, NIM is expected to measure most of the sputtered particle populations. Our calculations show that NIM's sensitivity is high enough to allow the detection of particles sputtered from the icy as well as the rocky surfaces, and to distinguish between different composition models, mainly by observing the presence or absence of CO and $CO_2$ and by determining the $N_2$ to $NH_3$ ratio.

## References

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