INTERACTION OF JUPITER'S PLASMA WITH THE GALILEAN MOONS

P. Wurz[1], A. Galli[1], and A. Vorburger[1],
[1]Physics Institute, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland; peter.wurz@space.unibe.ch

KEYWORDS:

Jupiter's icy moons, plasma-surface interaction, ice sputtering, icy moons exospheres, JUICE

INTRODUCTION

The Galilean moons are immersed in the plasma and particle environment of Jupiter's magnetosphere. The interaction of these particles with the surface of the moons results in the release of material from the surface into the exosphere. The JUpiter ICy moons Explorer (JUICE) mission of ESA will visit the three icy Galilean moons, Europa, Ganymede, and Callisto, to perform detailed measurements. Since these moons all have a water ice surface we studied the interaction of these plasma particles with water ice in laboratory experiments and modelled the resulting exospheres.

MAGNETOSPHERIC PLASMA

There are two particle populations in Jupiter's magnetosphere, which are of concern for this study. The first particle population is the thermal plasma, also called cold plasma, that is more or less co-rotating with Jupiter's rotation [1,2]. The ions are mainly composed of oxygen, sulphur and hydrogen, with relative abundances of H^+:O^{n+}:S^{n+} = 1:3:1.7. The electron density is slightly higher than the ion density, with averaged values of 200 electrons cm^{-3} versus 130 ions cm^{-3}. The second population is the energetic particle populations, also called hot plasma population, with their energy spectra reaching beyond 100 MeV particle energy [3,4,5]. The temperatures of the electrons and ions of the hot plasma population are quite high, with values of 1 keV for electrons and tens of keV for ions. The energy spectrum of the hot ions is generally modelled by a kappa distribution with characteristic energies of a few tens to hundreds keV, and a power-law tail modelling the ions forming Jupiter's radiation belt. The energy spectra for the ions and electrons of the cold and the hot plasma are shown in Figure 1 for the energy range of interest.

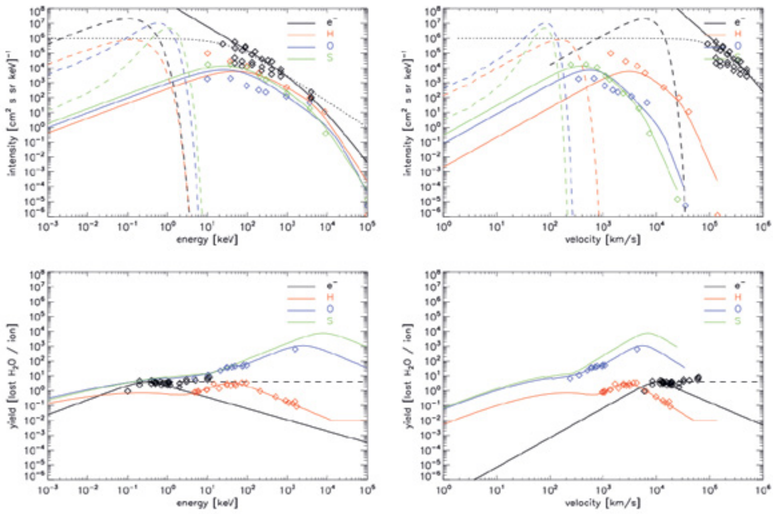

Fig. 1. Input data for exospheric modelling from [10]. Top row: Energy spectra for H, O, S ions, and e^- of the two plasma populations at Europa where points represent measurements and lines give modelled spectra. Bottom row: Sputter yields for water for H, O, S ions, and e^- for the energy (velocity) range of interest.

MAGNETOSPHERE-SURFACE INTERACTION

All these plasma populations cause sputtering of surface materials to populate the exospheres of the Galilean moons to various degrees. The neutral exosphere and the thermal plasma interact via charge exchange and electron ionisation, resulting in induced currents in the ionosphere (if existing), in mass loading of the plasma flow (pick-up ions), and in deflection of the plasma flow around the moon [6]. Deflection of plasma ions will reduce the plasma fluxes onto the moon's surface, thereby reducing the sputtering, and in turn the exospheric densities. Thus the moons exospheres and the magnetospheric thermal plasma are intimately coupled. These plasma-surface and plasma-exosphere interaction processes will all occur near the moon, at lengths scales commensurate with the scale height of the dominant exospheric species, thermal O_2. Some atoms and molecules escape from the moons atmospheres via gravitational escape and ionisation. In case of Europa these loss processes are significant, forming the Europa torus of neutral and ionised particles. Over time, these particles will become part of the plasma of Jupiter's magnetosphere.

EXPERIMENTAL STUDIES:

There are only a few studies reported in the literature related to sputtering of ice at temperatures relevant to the surfaces of Jupiter's icy moons. These studies were performed on thin layers of ice. However, on the icy moons an ice regolith surface is expected. Therefore, we set up a laboratory experiment to study the interaction of ions and electrons with ice regolith surfaces, with the ice at temperatures between 90 and 150 K to emulate the surfaces of the icy moons [7,8,9]. We studied sputtering by ions (H^+, O^+, O_2^+, O^{2+}, S^+, Ar^+, and Ar^{2+}) and electrons, measured the sputter yield and composition of the sputtered species, as well as surface charging and sublimation. The sputter yields for the ions (compiled from available literature) and electrons over the energy range of interest are shown in Figure 1. Ion sputter yields for water ice are much higher than for sputtering of minerals, even more so for heavier ions. Therefore, the hot plasma population, although of much lower density than the thermal plasma, contributes significantly to the total sputter yield. Also, the sputter yield of electrons is high already at low energies. Even though the electrons have a low mean energy related to their average movement with the co-rotation velocity, their temperature of about 100 eV is sufficient for a substantial sputter contribution to the exosphere [10].

EXOSPHERE MODELLING:

We calculate the contribution to the atmospheres of Europa, Ganymede, and Callisto by sputtering (using the two plasma types) and sublimation by modeling the formation of the moons atmospheres ab initio. As inputs to calculate the sputter contribution we use available energy spectra of plasma ions and electrons and the corresponding sputter yields (see Figure 1). Based on first principles we calculate atmospheric densities, without applying any scaling to observed data [10]. For Europa the particle release into exosphere is mostly

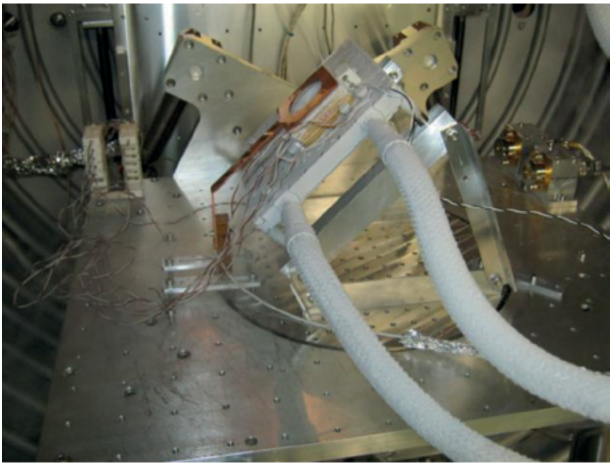

Fig. 2. Sample holder for regolith ice (with Cu ring) mounted on cryogenic stage, for ion irradiation experiments.

due to sputtering in about equal amounts by the thermal and the hot plasma. Since the plasma densities thin out with distance to Jupiter, the contribution by sputtering becomes less significant, and at Callisto the exosphere is mostly due to sublimation [11].

REFERENCES:

[1] Kivelson, M. G., K. K. Khurana, and M. Volwerk, Europa's Interaction with the Jovian Magnetosphere, 2009, p. 545.
[2] Bagenal, F., E. Sidrow, R. J. Wilson, T. A. Cassidy, V. Dols, F. J. Crary, A. J. Steffl, P. A. Delamere, W. S. Kurth, and W. R. Paterson, Plasma conditions at Europa's orbit, 2015, Icarus, 261, 1–13.
[3] Divine, N., and H. B. Garrett, Charged particle distributions in Jupiter's magnetosphere, 1983, J. Geophys. Res., 88, 6889–6903.
[4] Cooper, J. F., R. E. Johnson, B. H. Mauk, H. B. Garrett, and N. Gehrels, Energetic Ion and Electron Irradiation of the Icy Galilean Satellites, 2001, Icarus, 149, 133–159.
[5] Paranicas, C., R. W. Carlson, and R. E. Johnson, Electron bombardment of Europa, 2001, Geophys. Res. Lett., 28, 673–676.
[6] Rubin, M., X. Jia, K. Altwegg, M. Combi, L.K.S. Daldorff, T.I. Gombosi. K. Khurana, M.G. Kivelson, V.M. Tenishev, G. Tóth, B. van der Holst, and P. Wurz, Self-consistent multifluid MHD simulations of Europa's exospheric interaction with Jupiter's magnetosphere, 2015, Jou. Geophys. Res. 120, 1–22.
[7] Galli, A., A. Pommerol, P. Wurz, B. Jost, J.A. Scheer, A. Vorburger, M. Tulej, N. Thomas, M. Wieser, and S. Barabash, Surface charging of thick porous water ice layers relevant for ion sputtering experiments, 2016, Planet. Sp. Sci. 126, 63–71.
[8] A. Galli, A. Vorburger, P. Wurz, and M. Tulej, Sputtering of water ice films: a reassessment with singly and doubly charged oxygen and argon ions, molecular oxygen, and electrons, Icarus 291 (2017a) 36–45.
[9] A. Galli, A. Vorburger, P. Wurz, A. Pommerol, R. Cerubini, B. Jost, O. Poch, M. Tulej, and N. Thomas, 0.2 to 10 keV electrons interacting with water ice: radiolysis, sputtering, and sublimation, Icarus 291 (2017b), 36–45.
[10] Vorburger, A. and P. Wurz, Monte-Carlo Simulation of Europa's Exosphere, 2017, Icarus, submitted.
[11] A. Vorburger, P. Wurz, H. Lammer, S. Barabash, and O. Mousis, Monte-Carlo Simulation of Callisto's Exosphere, Icarus 262 (2015), 14–29.