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Measurement of the Atmospheres of Europa, Ganymede, and Callisto

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Abstract

The European Space Agency has selected the Jupiter Icy Moons Explorer (JUICE) mission to fly to the Jupiter system and to visit the icy moons Europa, Ganymede, and Callisto. One of the selected scientific instruments is the Particle Environment Package (PEP) that includes a Neutral gas and Ion mass spectrometer (NIM). NIM will measure the composition of the exospheres of these three moons during flybys and in orbit of Ganymede.

We present Monte Carlo calculations of Europa's exosphere including all relevant processes to release particles into the exosphere, which are sublimation, sputtering, and the plume release. For the surface composition we compiled composition data from existing spectroscopic observations and from formation models. We derive density profiles for different scenarios (e.g. day/night, in co-rotation flow, ...), and make predictions on the expected NIM measurements for the planned Europa flyby trajectories of JUICE .

1. Introduction

Within the core accretion model the regular Jovian satellites are formed at the end of Jupiter's formation epoch, from the collisional accretion of solids originating in the Solar Nebula, and captured in a disk orbiting around the planet. The solids taking part to the formation of the satellites therefore originate from the initial protoplanetary disk, and have probably experienced lower temperature and pressure conditions as has the material incorporated in Jupiter, and their chemical composition has been probably less altered. By measuring the composition of the Jovian satellites, it is therefore possible to constrain the chemical composition of building blocks of planets and satellites, and ultimately on the thermodynamical conditions in the Solar Nebula.

The PEP suite has been selected for the JUICE mission of ESA, which contains six instruments for the comprehensive measurements of electrons, ions and neutrals. One of these is the Neutral and Ion Mass spectrometer (NIM), which is a time-of-flight neutral gas and thermal ion mass spectrometer optimised for exospheric investigations. NIM mass spectra (1 – 1000 amu, m/Δm = 1100) are recorded with high cadence, between 1 s and 100 s. In a 5-s spectrum the detection threshold is 10^{-16} mbar (about 1 cm^{-3}).

2. Europa's Exosphere

Various physical processes are acting on the surfaces of Jupiter's icy moons to promote material from the surface into the exosphere. These are thermal desorption (sublimation), photon stimulated desorption, ion-induced sputtering, and micro-meteorite impact vaporisation [1,2], with sputtering being the most important surface release process [3]. Sputtering releases all species present on the surface more or less stoichiometrically into the exosphere, allowing directly deriving the chemical composition of the surface.

We modelled Europa's exosphere for the sputtered (SP) and the thermal component (th), after literature reports [4,5], which is shown in Figure 1. With the planned flyby of JUICE to a closest approach of 400 km many exospheric species can be sampled. The first exospheric signal will be observed already at a distance of 100'000 km.

Since the exospheres of Jupiter's icy moons are in direct contact with the surface of the respective moon, the chemical composition of the surface can be inferred from of the exospheric measurements. Knowing the chemical composition of the surface, and accounting for radiation induced chemistry at and near the surface, one can compare with models of the formation of these icy satellites from the protoplanetary disk from which Jupiter and the icy moons formed. In addition, if the JUICE flyby trajectory allows sampling the recently discovered plume on Europa [6] we can measure with NIM the composition of the underlying liquid body (perhaps Europa's ocean), which again can be compared to formation models, which would provide strong constraints on its formation conditions.

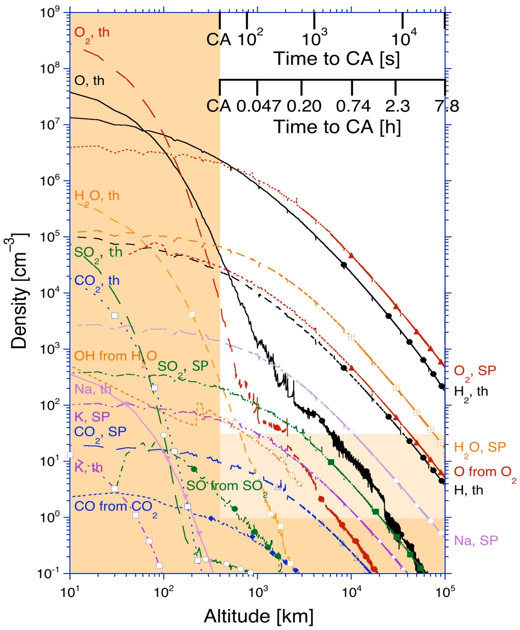

Figure 1: Calculated densities in Europa's exosphere at the dayside based on literature reports. White and light brown areas indicate the range of possible NIM measurements during Europa flyby. Left boundary is given by the 400 km flyby altitude at closest approach, lower boundary by the NIM sensitivity. The light brown area corresponds to the increased background from the penetrating radiation.

3.1 NIM Flyby Operations

Typically, NIM records full mass spectra at a cadence of 100 s. Within 1 hour of the closest approach the cadence will be increased to 5 s per mass spectrum. Because of the background from penetrating radiation at Europa's orbit the detection threshold is lowered to 30 cm^{-3}, which still allows for a dynamic range of > 10^5 at closest approach (see Figure 1).

All species presently known in Europa's exosphere can be detected by NIM/PEP during the JUICE flybys, which are O, O_2, H_2, H_2O, Na, SO_2, SO, CO_2, CO. In addition, exospheric species from non-ice surface will be detected if their surface abundance is >= 10^{-3}. Possible candidates for such exospheric species are Mg, MgO, NaO, Ca, CaO, Al, AlO, which are sputtered from their respective minerals.

With a threshold of 30 cm^{-3} and a dynamic range of > 10^5 the D/H ratios can be measured in the thermal component of H_2, also $^{18}O/^{16}O$ from the O_2 and H_2O in the sputtered signal.

4. Europa Neutral Torus

The density in Europa's neutral torus was modelled by Smith and Marconi [4] for H_2 and O. At Europa the neutral torus is more than 1 Jupiter radius wide (R_J). With the nominal JUICE trajectory there are at least two opportunities when the S/C flies through the torus: 1) during 4 November 2030 18:00 – 5 November 2030, 12:00, with the innermost point at 10.0 R_J, latitude of 0.1°, and a distance to Europa of 18 R_J (i.e., JUICE in conjunction to Europa and Io); and 2) during 3 April 2031, 19:00 – 4 April 2031, 02:00, with the innermost point at 10.8 R_J, latitude of 0.0°, distance to Europa of 7 R_J. From the model [4] we estimate that for the first passage the expected densities are ~ 10 cm^{-3} and < 1 cm^{-3} for H_2 and O, respectively. For the second passage we estimate densities of ~ 10 to 100 cm^{-3} and ~ 5 cm^{-3} for H_2 and O, respectively. Thus, NIM / PEP will be able to make useful measurements of the composition of Europa's neutral torus; data which will also be useful to deconvolve the energetic neutral atom (ENA) images recorded by JNA and JENI of PEP.

Acknowledgements

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