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Plasma IMS Composition Measurements for Europa and Ganymede

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Abstract

NASA and ESA are planning the joint Europa Jupiter System Mission (EJSM) to the Jupiter system with specific emphasis to Europa and Ganymede, respectively. The Japanese Space Agency is also planning an orbiter mission to explore Jupiter's magnetosphere and the Galilean satellites. For NASA's Jupiter Europa Orbiter (JEO) we are developing the 3D Ion Mass Spectrometer (IMS) with two main goals which can also be applied to the other Galilean moons, 1) measure the plasma interaction between Europa and Jupiter's magnetosphere and 2) infer the 4π surface composition to trace elemental [1] and significant isotopic levels. The first goal supports the magnetometer (MAG) measurements, primarily directed at detection of Europa's sub-surface ocean, while the second gives information about transfer of material between the Galilean moons, and between the moon surfaces and subsurface layers putatively including oceans. The measurement of the interactions for all the Galilean moons can be used to trace the *in situ* ion measurements of pickup ions back to either Europa's or Ganymede's surface from the respectively orbiting spacecraft. The IMS instrument, being developed under NASA's Astrobiology Instrument Development Program, would maximally achieve plasma measurement requirements for JEO and EJSM while moving forward our knowledge of Jupiter system composition and source processes to far higher levels than previously envisaged.

1. Introduction

The composition of the global surfaces of Europa and Ganymede can be inferred from the measurement of ejected neutrals and pick-up ions using at minimum an *in situ* payload including MAG and IMS also fully capable of meeting Level 1 mission requirements for ocean detection and survey. Elemental and isotopic analysis of potentially extruded oceanic materials at the moon surfaces would further support the ocean objectives. These measurements should be made from a polar orbiting spacecraft about Europa or Ganymede at height ~ 100 km. The ejecta produced by sputtering of the surfaces of Europa and Ganymede has been shown to be representative of the surface composition [2, 3]. Level 2 science on surface geology and composition can then be further enhanced by addition of the following: 3D Ion Neutral Mass Spectrometer (INMS), 3D plasma electron spectrometer (ELS), and hot plasma energetic particle instrument (EPI).

1.1 Measurement Technique

The measurement approach is to alternate between times measuring pickup ions and times measuring plasma and magnetic field parameters along the spacecraft trajectory. By measuring the pickup ion energy, arrival direction and mass-per-charge, the ion can be traced back along the ejection trajectory to the approximate area of origin if the 3-D electric field and magnetic field are known. *In situ* observations of plasma flow velocities and vector magnetic fields can be used to determine the local convective electric field (**E = -VXB**) along the spacecraft trajectory. By combining this information with models of the magnetospheric interaction with Europa [3,4], one can generate 3D maps of the electric and magnetic field and compute the trajectories of the pickup ions as test particles back to the surface or exospheric points of origin. In the case of Ganymede there is the additional complexity of its own internal dipole magnetic field.

1.2 Other Measurement Issues and Supporting Measurements

The exosphere and ionosphere of Europa can be quite complex and patchy. We show that the exobase and ionopause are almost always below the orbiting spacecraft altitude ~ 100 km for Europa. This estimation is based on an exosphere model of the O_2 atmosphere, shown in Figure 1, using O_2 atmosphere parameters in [5] and exosphere formula in [6]. Then using similar approach in [7] we compute the "ionopause" heights and their relation to spacecraft height at 100 km as shown in Figure 2 for various impact parameters b for upstream flow (i.e., b = 0 indicates flow at nose of interaction and b = 1560 km indicates flow along flanks). Reference [5] shows the O_2 peaks near Europa's trailing side so one expects neutral densities to be low along flanks.

The proposed technique can only sample ions above the "ionopause" where the magnetospheric electric field can penetrate and accelerate the newly born ions up to the spacecraft position where they can be observed. When the ion gyro-radius is $R_g > ½$ the spacecraft altitude of 100 km [8], these ions can be traced down to the spacecraft surface if the "ionopause" penetrates to such depths (i.e., low O_2 neutral density regions < 10^8 mol/cm^3 at surface). If the "ionopause" is at higher altitudes one can use the observed energy spectrum of the pickup ions and width if peak present to measure the atmospheric scale height and then extrapolate down to the surface (i.e., a narrow peak indicates small scale height relative to the ion gyro-radius or $\alpha = R_g/H >> 1$ [8] which is true for O_2). In reality the picture is more complex and a 3D Hybrid code is needed to construct more realistic 3D maps of the electric and magnetic fields. One can then use regions of known composition from imaging spectrometers to calibrate the technique and thus the global 3D electric and magnetic fields which can then be used to measure and map to the surface more minor species that the imagers cannot hope to detect.

We will show using the model calculations for pickup ion phase space densities [8] and exosphere model for the O_2 atmosphere (see Figures 1 and 2) that the ionosphere at spacecraft altitude and higher is dominated by O_2^+ pickup ions and that ion temperatures are T ~ 100-1000 eV. Comparisons are made with Galileo Radio Science observations by [9].

In the case of Ganymede its internal magnetic field complicates the analysis. Galileo observations do show evidence of a polar wind [10] where the field lines are open so one could infer surface composition in the polar regions by measuring the polar wind composition. For this analysis one must construct 3D MHD or Hybrid models of Ganymede's magnetosphere interaction with Jupiter's magnetosphere since transport time scales can be relatively short ~ 1 hour or less and polar cap transport of ionospheric plasma can become mixed with a return flow of Jovian magnetospheric plasma from Ganymede's magnetic tail and thus complicate the surface composition measurements near equatorial latitudes.

Finally, the INMS observations and neutral exosphere models are needed to estimate production rates of pickup ions since we're measuring the sputtered exosphere and need this last step to measure surface composition levels. The hot plasma measurements are needed to correct for sputtering rates which can be time dependent and electron plasma observations for electron impact ionization rates. Instrument characteristics, field-of-view requirements, modes of operation and effects of radiation on instrument functionality will be discussed.

3. Figures

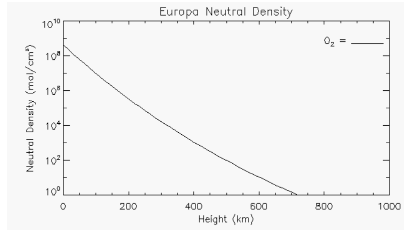

Figure 1: Europa O_2 exosphere model based on atmosphere parameters in [5] and exosphere formula in [6].

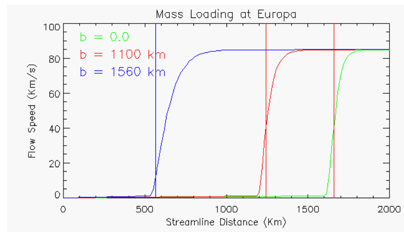

Figure 2: Mass loading calculation of external flow interacting with Europa's O_2 exosphere as shown in Figure 1 and using photoionization, electron impact ionization and charge transfer reaction rates as described in [7] for Titan. The parameter b is impact parameter of external flow relative to nose of interaction b=0. Vertical lines indicate spacecraft position at 100 km altitude.

6. Summary and Conclusions

We present a measurement technique using an IMS being developed under the NASA Astrobiology Instrument Development Program, to measure goal 1 the plasma interaction between Jupiter's magnetosphere and its moons Europa, Io, Ganymede and Callisto. In the case of Europa it will support the magnetometer's detection of its sub-surface ocean. The second goal is to constrain surface composition, chemistry and space weather effects on the surfaces of the moons Europa and Ganymede. This IMS, being developed for the JEO spacecraft, is designed to operate in a high radiation environment with minor ion detection capability. The latter goal is achieved by measuring pickup ions at spacecraft altitudes and using a 3D hybrid model of the interaction in order to construct 3D global model of the electric and magnetic fields around these bodies so the pickup ion trajectories can be traced down to the surface. In the case of Europa we also show that Europa's ionosphere is dominated by pickup ions with 100-1000 eV temperatures and excursions to a "classical" cold ionosphere for the INMS is expected to be infrequent.

Acknowledgements

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