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Surface charging of JUICE spacecraft at Ganymede and Europa

F. Cipriani (1), D. Rodgers (1) and A. Hilgers (1)
(1) ESA/ESTEC, Noordwijk, The Netherlands, (fabrice.cipriani@esa.int / Fax: +31-71-5658649)

Abstract

We use the Spacecraft Plasma Interaction Software to carry out 3D PIC simulation of JUICE spacecraft charging both in the Jovian magnetosphere at Ganymede and Europa's orbits, and in the vicinity of Ganymede and Europa. This is useful in order to study how the S/C surface potentials might affects the detection of low energy particles in general and observe the influence of the close environment of the Moons on the S/C potential and wake structure.

1. Introduction

ESA/JUICE mission is set be launched in 2022 and if so is expected to start exploring Jupiter system and the Galilean moons in 2030. JUICE will spend about 3 years in Jupiter magnetosphere and penetrate as deep as Europa's orbit. Following current mission scenario, respectively 282, 200, and 36 days will be spent in various orbits/flyby of Ganymede, Callisto, and Europa. In this context, in order to support JUICE spacecraft design on the one hand and optimize plasma instruments accommodation on the other hand, we have built a numerical model of JUICE spacecraft based on 3 potential configurations. This is in order to 1) estimate surface charging levels of JUICE both at Ganymede and Europa's orbits in the Jovian plasma including worst case analysis, 2) estimate how the close environment of those Moons affects the surface charging, and 3) characterize the spacecraft wake structure in those various environments and its influence on low energy particles measurements.

1.1 Model overview

We carried out 3D PIC and PIC-PIC simulations of the interactions between the JUICE and the plasma environment at Jupiter using the Spacecraft Plasma Interaction Software (SPIS) [3].

The S/C was modeled as a simplified orbiter integrating solar panels (CERS/CFRP), high gain antenna (White Paint/ITO), s/c body (ITO), thruster, electrical and magnetic booms, and small area patches allowing to study charging of small (insulating) areas under diverse conditions.

We performed simulations within 2 calculation domains. One is a rectangular box of 100mx60mx30m meshed in $2x10^5$ tetrahedrons. The other is an ellipsoid which has axis lengths of 200mx160mx40m, and is meshed in $3x10^5$ tetrahedrons. At Ganymede's orbit the electrons Debye length is close to 10m while around 1m in the secondary electron sheath. At Europa's orbit, the Debye length is close to 3m. In both cases we use a mesh resolution of (up to) 0.5m on the whole S/C, up to 5m at the domain boundary. We generally carried out simulations using PIC ions populations and fluid (Maxwell-Boltzmann) electrons, in order to speed up the simulation time, as long as the S/C is expected to charge negatively. However PIC-PIC simulations have also been used in order to compare methods and check the consistency of our outputs. The plasma environments considered for charging at Ganymede and Europa have be defined in agreement with observations and models based on previous Voyager and Galileo data at Jupiter (see e.g. [4]).

2. JGO Charging levels

2.1 At Ganymede's orbit

In order to be able to compare our outputs with previous charging analysis [1, 2] we have used Jupiter's magnetosphere environment data at Ganymede's orbit based on GIRE model estimates at equatorial latitude and 110° west longitude (SIII coordinates). Similarly our worst case environments at Ganymede corresponds to the two types of auroral electrons distributions as defined and used by Garrett et al [1].

Secondary emission clearly drives the charging equilibrium as photoemission is significantly less efficient at Jupiter's distance than it is at Earth. As summarized in Table 1 the results obtained for different spacecraft configurations (plasma corotation direction, illumination axis) suggest that :

- based on our assumptions on secondary emission levels, the ITO covered s/c body charges a few volts negative (down to -10V) in average (non-worst case) conditions. However in practice, a few volts positive or negative can be expected as a function of local time and s/c orientation, and material properties.
- the orientation of the s/c wrt the corotating plasma has a weak influence on the spacecraft absolute potential, including the potential of insulating patches. The latter is mostly driven by secondary emission resulting from primary electrons impact.
- worst case simulations in auroral conditions show significant discrepancies with previous estimates [1]. JGO s/c body is charging downto ~ -14kV (-30kV in more realistic rarefied auroral environment). This is due to the implementation of a 3D s/c model including large area (~40m^2) cover glass which collects a large fraction of the ion current that do not contribute to the current balance. In such case differential charging between front (CERS) and back (CFRP) sides of the solar panels reaches up to 1kV.
- consistently with the previous point in the presence of full illumination of the solar panels worst case surface potentials are reduced by a factor of ~3, which then gives charging levels comparable to estimates in [1].
- worst case diffuse auroral environment defined by Kappa distributions and an energy input of ~15erg/cm.s-1 results in s/c body surface potential of about -220V.

2.2 At Europa's orbit

In order to be able to perform simulations at Europa's orbit we defined a plasma environment based on Io's torus model of Moncuquet et al [5]. We also defined a 'preliminary' worst case 'Storm like' environment based on plasma injections events observed by Galileo/ EPD at all longitudes from approximately Europa's to Callisto's orbits (see e.g. Mauk et al [6]). As shown in Table 1 due to denser and more energetic electrons populations at Europa compared to Ganymede JGO s/c body equilibrium potential is about -30V. In the presence of more energetic populations (worst case situation), whose description requires further refinement, using 0.1cm^{-3} hot electrons and 0.8cm^{-3} hot ions at 20keV energies results in the s/c body significantly charging down to -6240V (tentative value).

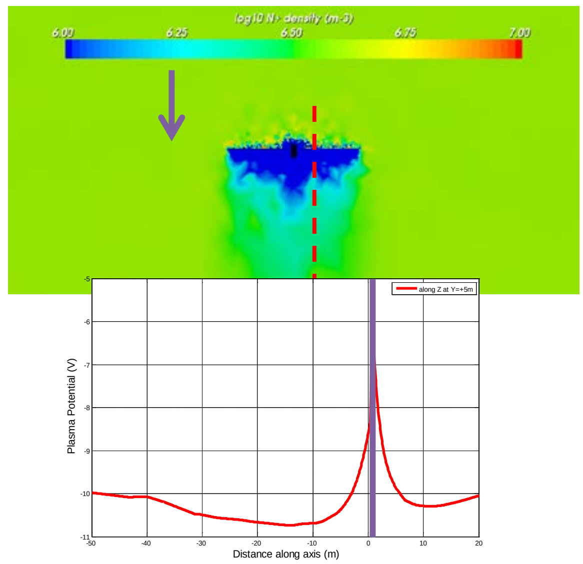

Figure 1: Upper panel : cold ions density at Ganymede (flowing along the Z axis) around JUICE simplified model implemented in SPIS. A density threshold of 10^{6}cm^{-3} is set in order to better visualize the wake. Bottom panel: potential profile along the Z axis crossing the Solar Panels plane (thick vertical line) at Y=+5m (dashed red line on the upper panel).

Table 1: Table I. Partial results of JGO charging simulations, *excluding cases in Ganymede and Europa close environments* (** Values to be refined).

Simulated Orbit/sector	S/C body (ITO) Potential (V)	Solar Panel Cover glass Potential (V)
Ganymede SUN ON	-5.13	-1.12
Ganymede SUN OFF SEE OFF	-2296	-2221
Ganymede SUN OFF (*PIC-PIC)	-5.42 (*-12.1)	-1.54 (*-3.2)
Ganymede SUN OFF / JGO Aluminium	-20.13	-0.16
Ganymede Worst Case I	-15500	-14400
Ganymede Worst Case II (ions density/10)	-31280	-30760
Ganymede Worst Case with photoemission	-4930	-3500
Ganymede diffuse aurora	-222	-209
Europa eclipse	-27.5	-2.4

Europa eclipse Storm like	-6240**	-5500**

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