SPIS simulations of JUICE spacecraft charging and implications for particle measurements in Europa's ionosphere and the Jovian magnetosphere

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Abstract

We present Spacecraft Plasma Interaction Software (SPIS) simulation results of the Jupiter Icy Moons Explorer (JUICE) spacecraft charging in the ionosphere of Europa, at 400 km altitude, and in the Jovian magnetosphere, at 9.5, 15, and 26.3 R_J. The simulation results indicate that surface charging is of minor importance for typical Jovian magnetospheric conditions, but large amounts of secondary electrons and photoelectrons will provide challenging data analysis problems. In addition, large surface and differential charging will complicate cold plasma and electric field measurements in the ionosphere of Europa.

1. The ionosphere of Europa

JUICE will perform at least two Europa flybys, currently scheduled on September 17 and October 1, 2030. As simulation input we use the flyby ephemeris and spacecraft attitude for the closest approach and environmental parameters obtained from Galileo plasma and magnetic field measurements and models of the Europa ionosphere, presented in Table 1.

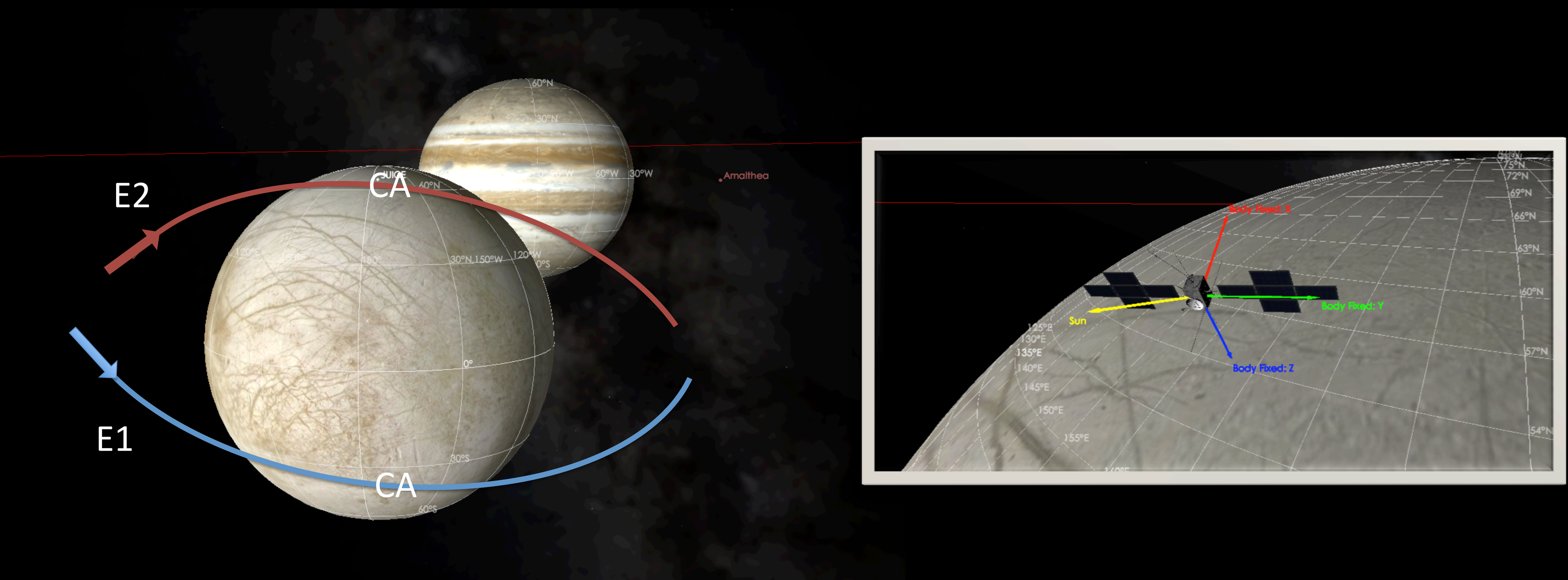

Figure 1. Left: Sketch of the JUICE Europa flybys, E1 (blue) and E2 (red) according to the trajectory version Crema 3.2. Closest approach (CA) for both flybys are 403 km. Right: Spacecraft attitude for E2, including the direction of the Sun (yellow) and the spacecraft coordinate system X (red), Y (green), and Z (blue) .

Parameter	Value	Estimate and range	Reference
n_e	200 cm^{-3}	**2500** (200-5000, from occultation), **110** (E6 at 586 km), **110** (E6 at 586 km) **600** (E12 at 201 km, possible plume) and **40** (E26)	Kliore et al. 1997, Gurnett et al. 1998, Kurth et al. 2001
T_e	20 eV	10-30 (ambient), 35 (E4)	Bagenal et al. 2015, Rubin et al. 2015
n_i	200 cm^{-3} ($n_i \approx n_e$)	**30** (E06 at 586 km), **25** (E4 and E26)	Paterson et al. 1999, Rubin et al. 2015
T_i	90 eV	**260** (E06 at 586 km), **90** (E4)	Paterson et al. 1999, Rubin et al. 2015
$v_{i,\theta}$	60 km/s	**60** (E4)	Rubin et al. 2015
Ion species	O^+	O^+, O^+ (above ~300 km)	Paterson et al. 1999, Rubin et al. 2015
$\|v_{s/c}\|$	17.2 km/s		Crema 3.2 trajectory data
$\|B\|$	480 nT	420, (ambient) 500 (E4, pile-up), 480 (at 513 km, pile-up)	Showman and Malhotra 1999, Rubin et al. 2015, Kivelson Moon/magnetosphere workshop 2019

Table 1: The environment parameters for Europa's ionosphere at 400 km. The table includes an estimate of electron density n_e and temperature T_e, ion density n_i and temperature T_i, ion azimuthal velocity $v_{i,\theta}$, spacecraft velocity $v_{s/c}$, and magnetic field B, obtained from the references listed in the right column.

2. JUICE ion wake and surface charging

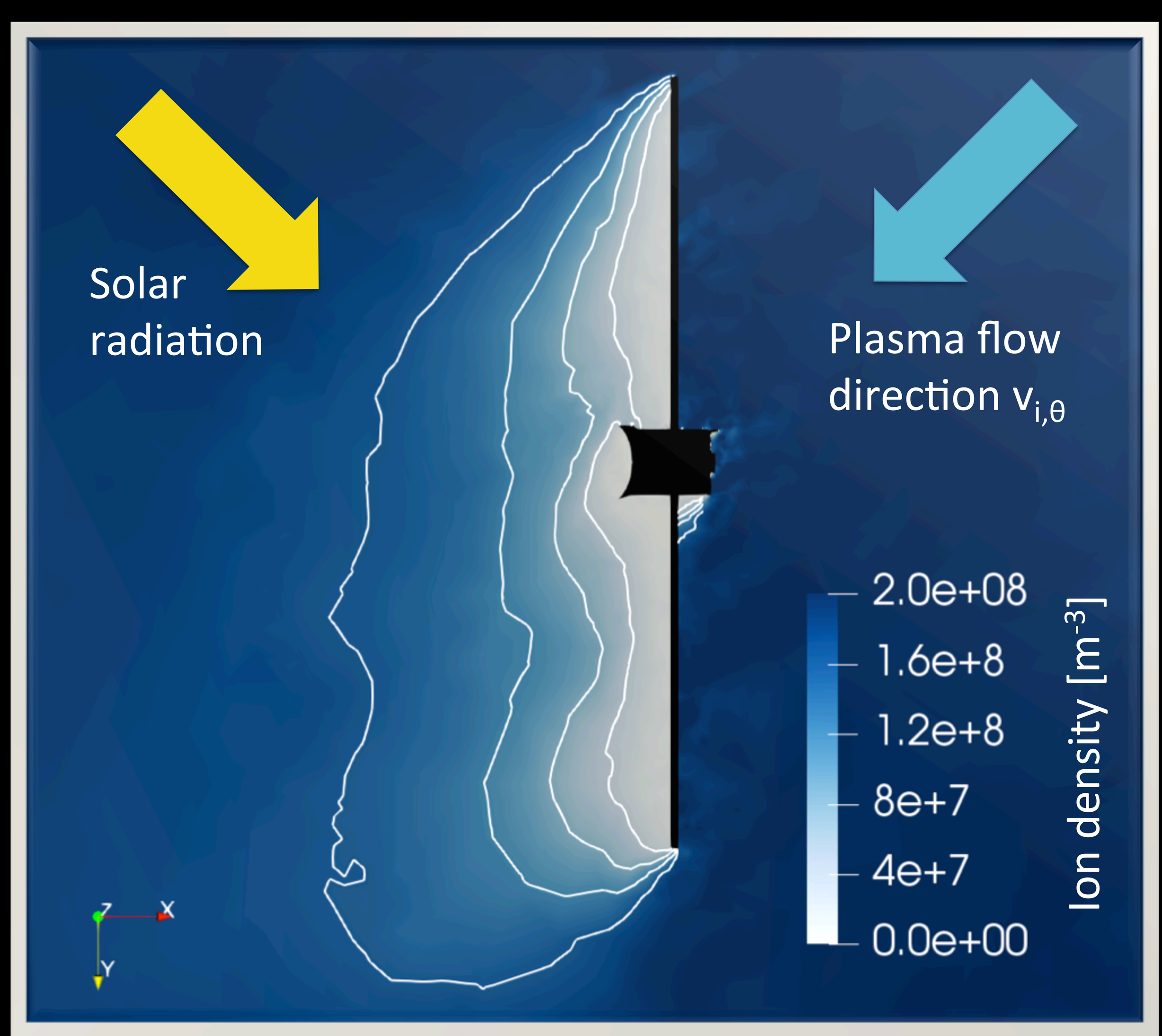

Figure 2: When the speed of the spacecraft, relative to the plasma, exceeds the thermal speed of the ambient plasma a depletion of ions, an ion wake, will form behind the spacecraft. This figure shows a cross-section of the simulated ion wake of JUICE in the ionosphere of Europa at around 400 km for flyby E2.

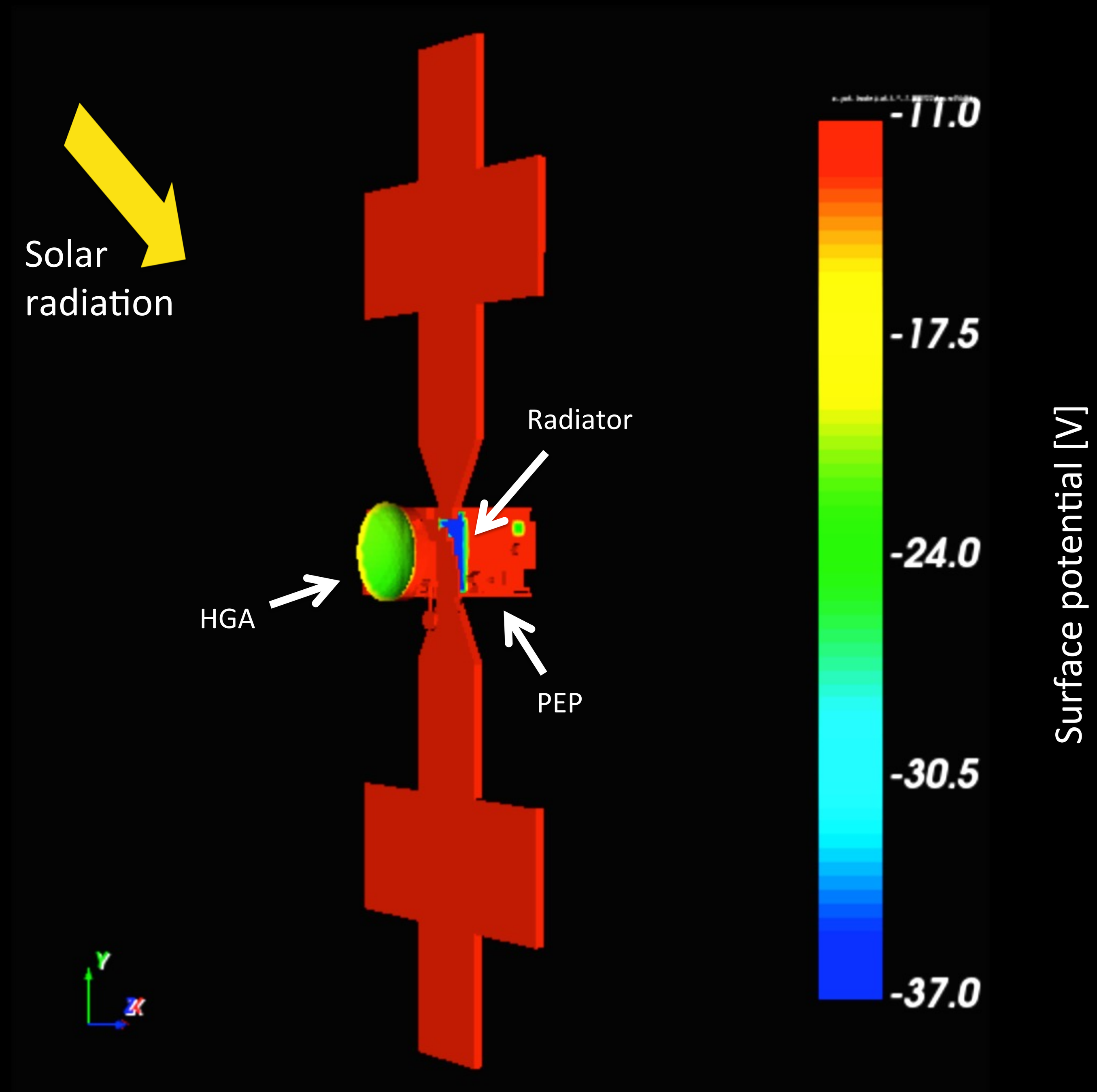

Figure 3: The simulated surface potential of JUICE in the ionosphere of Europa at around 400 km for flyby E2. The spacecraft body and the solar panels charged to -11 V, the high gain antenna (HGA) to -22 V and the top vault radiator to -37 V.

The JUICE spacecraft charging in the ionosphere of Europa at 400 km was also simulated including a putative hot electron component, with n_e= 1.3 cm^{-3} and T_e=250 eV, which is obtained from the magnetospheric measurements at 9.5 R_J, close to the orbital distance of Europa. The hot electrons produce an increased amount of secondary electrons which will make the spacecraft surface potential more positive. For the simulations including the hot electron component the spacecraft body and the solar panels charged to -11 V, the high gain antenna to -14 V, and the top vault radiator to -24 V.

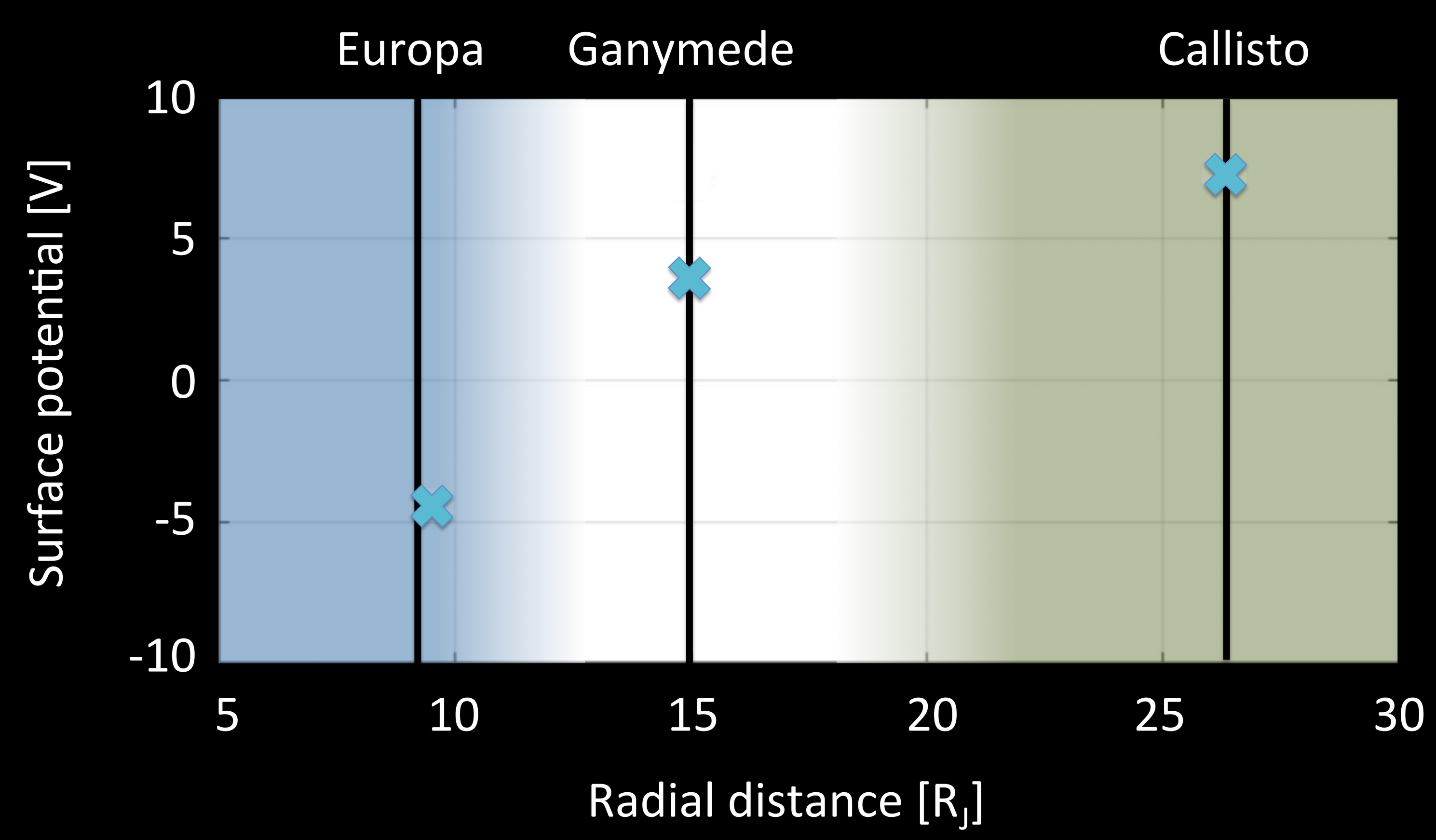

Figure 4: The spacecraft charging was also simulated for three different Jovian magnetospheric environments, at 9.5, 15, and 26.3 R_J. The blue markers gives the average surface potential for each distance. The blue region represents negative spacecraft potential and a dominant ambient electron current, the white region represents positive surface potential and a dominant secondary electron current, the green region marks the region where the currents are dominated by the photoelectron current.

3. Implications for JUICE particle measurements

The surface charging of JUICE will limit the ability of the particle instrumentation to measure the cold plasma, for the studied environment. Electrons with E < -11 V will be repelled before they are able to reach JUICE. In addition, the close proximity of the strongly charged top vault radiator with the PEP instruments will prevent PEP/JEI from measuring the majority of the cold plasma electrons in Europa's ionosphere. A differential charging of between -13 and -26 V will complicate the electric field measurements since the potential structure around the spacecraft will not be uniform. This study shows that the surface charging of the spacecraft may limit the ability of JUICE to accurately characterise the ionosphere of Europa.