SPIS Surface Charging Analysis for JUICE

DEFENCE AND SPACE

Dr.-Ing. Christian Imhof
06. April 2017

AIRBUS

Outline

- JUICE – Satellite and Mission overview
- Satellite modelling in SPIS
- Plasma environment definition
- SPIS settings
- Simulation Results
- Conclusions

JUICE – Satellite and Mission overview

- JUICE – Jupiter Icy moons Explorer
  - L-class mission in ESA’s Cosmic Vision Programme
  - Envisaged launch in 2022
- Trajectory
  - Fly-bys at Callisto and Europa
  - Final orbit around Ganymede
- Scientific Mission
  - Total of 11 scientific instruments will be hosted on the satellite
  - Exploration of possible life habitats beneath the ice layers of the icy moons Callisto, Europa and Ganymede
  - Observation of Jupiter’s atmosphere and magnetosphere including the plasma environment

JUICE – Satellite and Mission overview

- Plasma and Particle Sensors installed on the JUICE satellite
  - JMAG
    - Composed of two flux gate magnetometers and one scalar magnetometer (design drivers for DC magnetics)
    - Driving instrument for the long boom to decouple the sensitive magnetometers from the magnetic disturbances by the platform
  - RPWI – Radio Plasma Wave Instrument
    - 4 Langmuir Probes (LP) spread around the satellite
    - 3 perpendicular electrical dipole sensors; located on the boom for enhanced decoupling from field emitted by the satellite
    - One search coil magnetometer (design driver for AC magnetics)
  - PEP – Particle detectors
    - 6 particle detectors spread over the satellite to cover 4π sr around the satellite
    - Electrons as well as ions are detected

- The efficient use of these instruments with maximum science return demands very stringent requirements to the platform in terms of electrical cleanliness
  - For surface charging the goal is to suppress any differential charging on the satellite to a level below 1 V
    - Very challenging goal since also other requirements (e.g. thermal) are very demanding

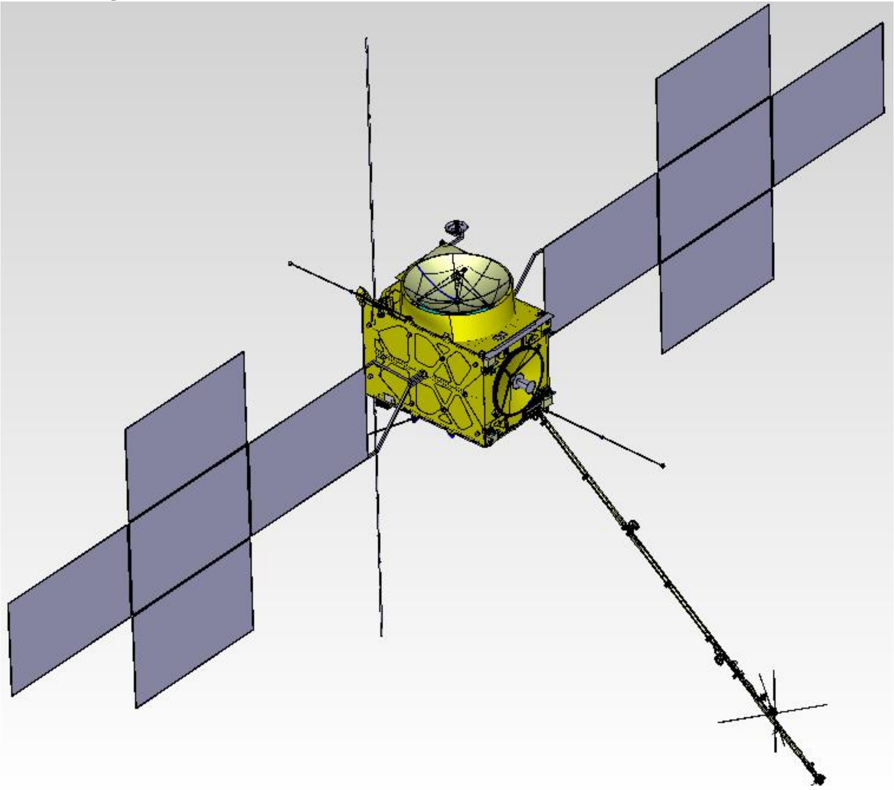
JUICE – Satellite and Mission overview

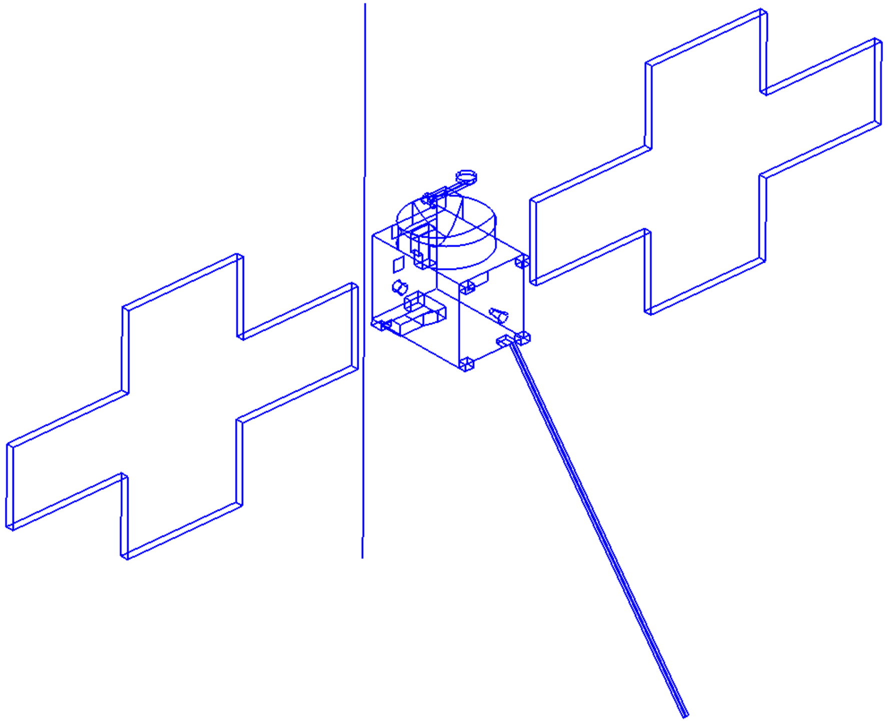
- Special Design measures taken to minimise the differential charging on the satellite
  - Use of ITO coated cover glasses without any AR coating
    - AR coating could charge up to several 10s of volts if applied
  - Careful selection of the different surface materials like MLI and radiators
    - Black Kapton® baselined for the standard MLI
    - High temperature MLI material selection is still on-going
    - Radiator & HGA paint material selection is difficult since the thermal requirements are also demanding due to Venus fly-by

- Satellite surface charging analysis using SPIS is needed in order to show the global behaviour of the satellite with respect to the requirements
  - Material selection represents the current status
  - Several critical materials are still on the satellite
  - Analysis results needed for the discussion with several suppliers to push for selection of better materials

Satellite Modelling for SPIS

- Several simplification have been introduced in the SPIS model in order to get a suitable model
  - LP and other very small details are not modelled in the current design
  - SA panels are modelled with increased thickness to get a better mesh quality on the edges
  - RIME dipole antenna is modelled using the thin wire approach
  - Only the instrument boom but none of the details on the boom are modelled

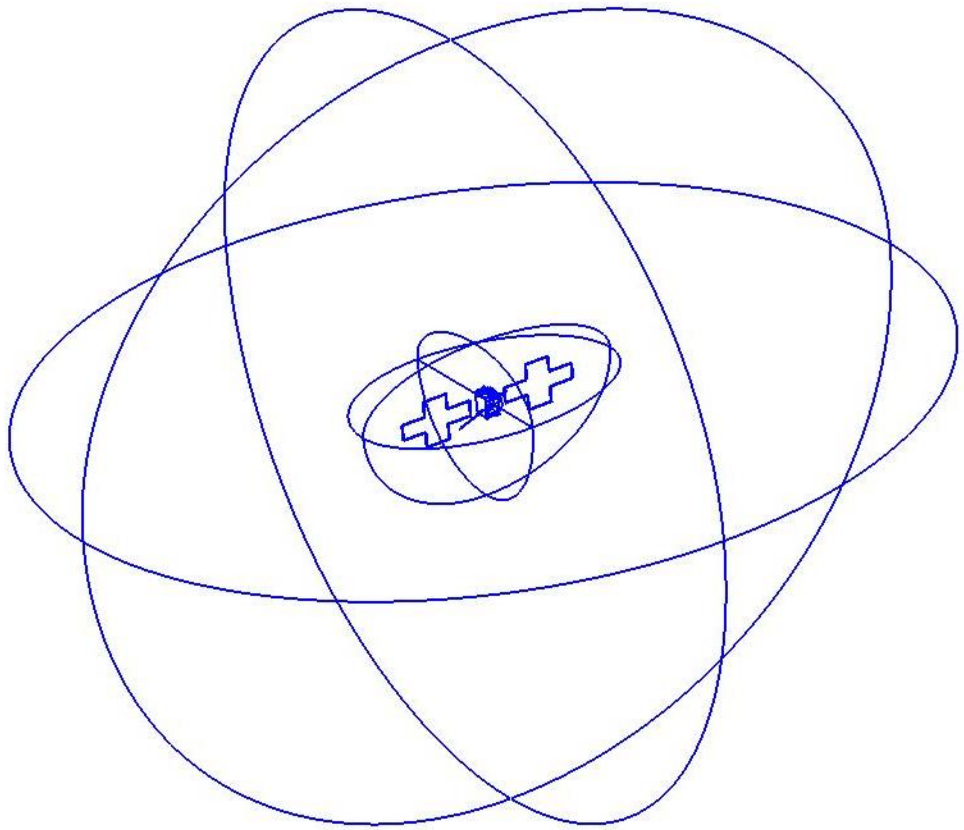




AIRBUS

Satellite Modelling for SPIS

- Simulation volume modelling
  - Two volumes are defined for a better mesh refinement
  - Diameters of the outer simulation volume
    - X-direction: 130 m
    - Y-direction: 144 m
    - Z-direction: 125 m
- Mesh statistics
  - ≈ 12400 nodes on surfaces
  - ≈ 263000 tetrahedrons in the volume
  - ➢ total memory demand of > 10 GB with simulation time of roughly one day

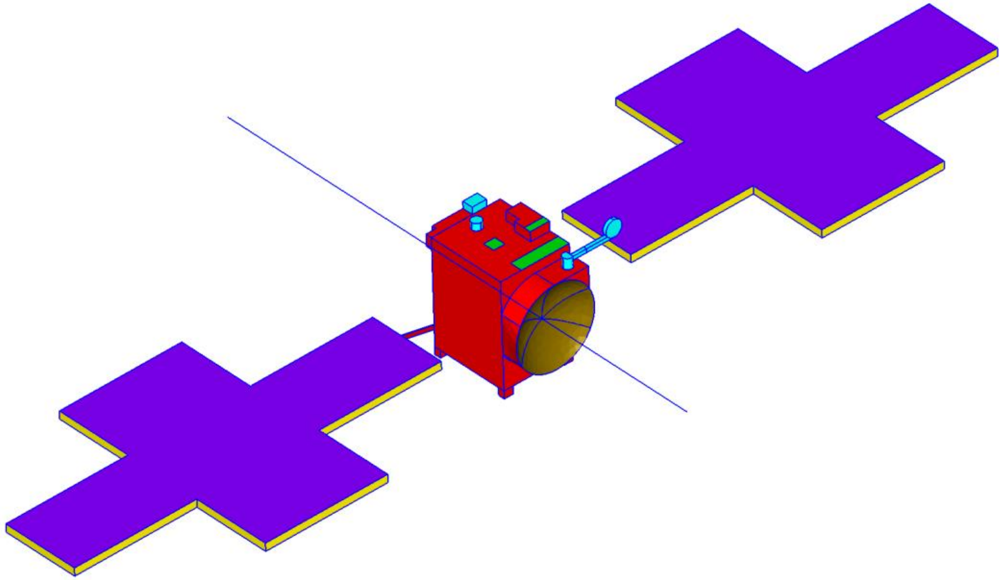


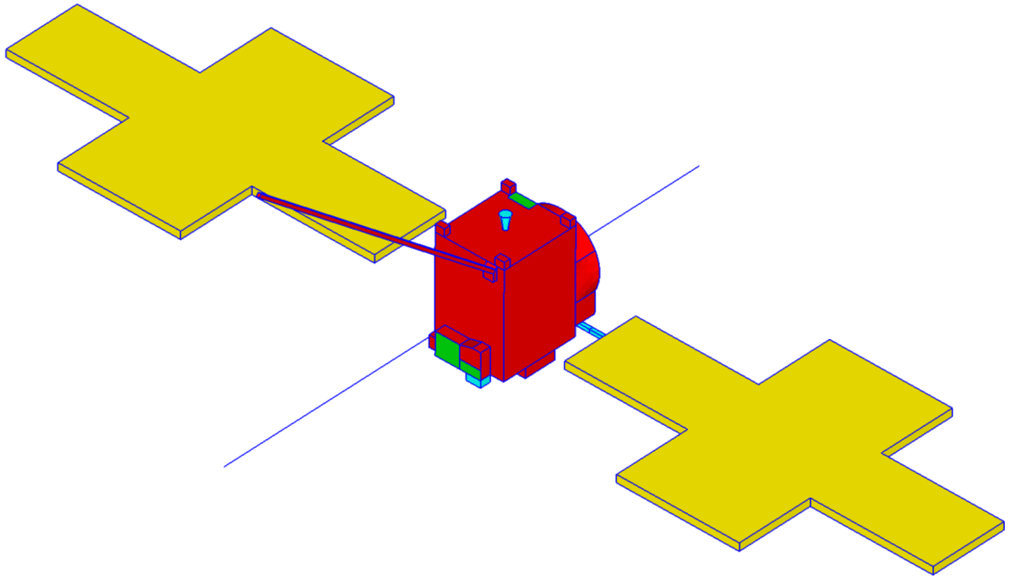
Satellite Modelling for SPIS

- Material Distribution
  - Critical elements with respect to the 1 V requirement
    - Rear side of the SA
    - Radiators
    - Thermal Paint on the HGA antenna

Colour	Description	Material	SPIS Material	Node #
Blue	RIME; CFRP	CFRP; Epoxy	Epoxy, t = 50 µm	0 (Ground)
Red	MLI	Black Kapton®	Black Kapton	1
Green	Radiators	PSG121FD	SG120; σ = 4.5e-15 S/m; t = 50 µm	2
Cyan	Thruster / MGA	Titanium	Steele	3
Brown	HGA Reflector	PCBE	PCBE; σ = 5.3e-15 S/m; t = 50 µm	4
Purple	SA cover glasses	ITO	ITO	5
Yellow	SA rear panel	CFRP; Epoxy	Epoxy, t = 50 µm	6

Conductivity values of the paint materials are selected based on measurements at ONERA performed in the frame of an Airbus internal TDA for JUICE





Plasma Environment Definition

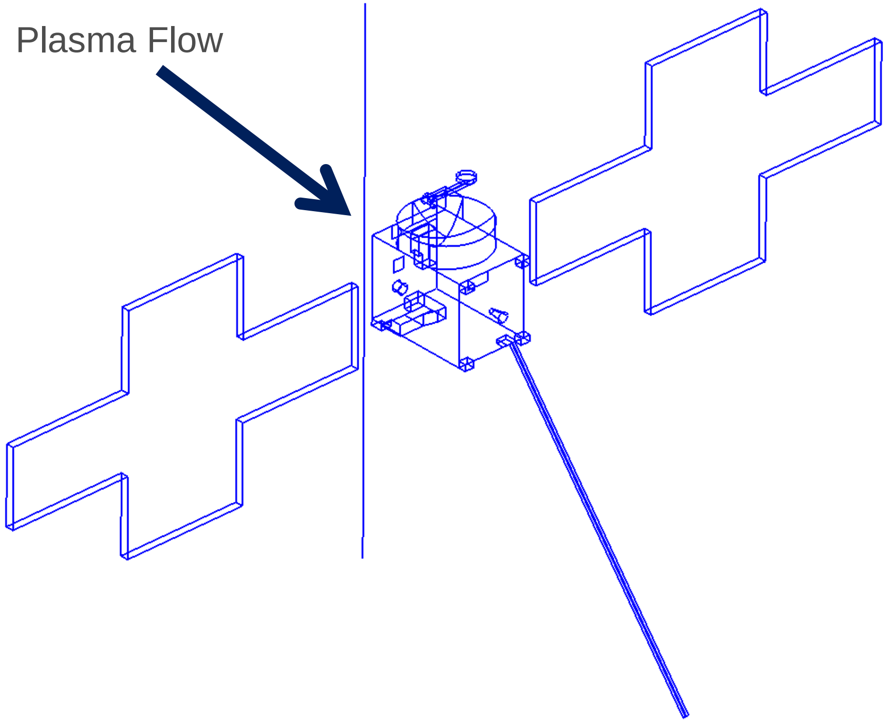
- Various possible worst case plasma definitions have been extracted from the environment specification
  - Two auroral definitions for the Ganymede orbit
  - One auroral definition for the Callisto orbit applicable for the fly-bys

Parameter	Ganymede Maxwellian Aurora	Ganymede Kappa Auroral	Callisto Kappa Auroral
N_{e1} / cm^{-3}	0.8	0.8	0.736
T_{e1} / eV	25	25	26
v_{Drift} / km/s	158	158	200
N_{i1} / cm^{-3}	1.483	1.483	0.779
T_{i1} / eV	350	350	26
v_{Drift} / km/s	158	158	200
Ion Type	O+	O+	O+
N_{e2} / cm^{-3}	1.024	1.024	0.064
T_{e2} / eV	1000	1000	1000
N_{i2} / cm^{-3}	0.341	0.341	0.021
T_{i2} / eV	30000	30000	30000
Ion Type	H+	H+	H+
N_{e3} / cm^{-3}	0.57	2.0	0.3
T_{e3} / eV	25000	1500	3200
κ	-	2.4	2.4

AIRBUS

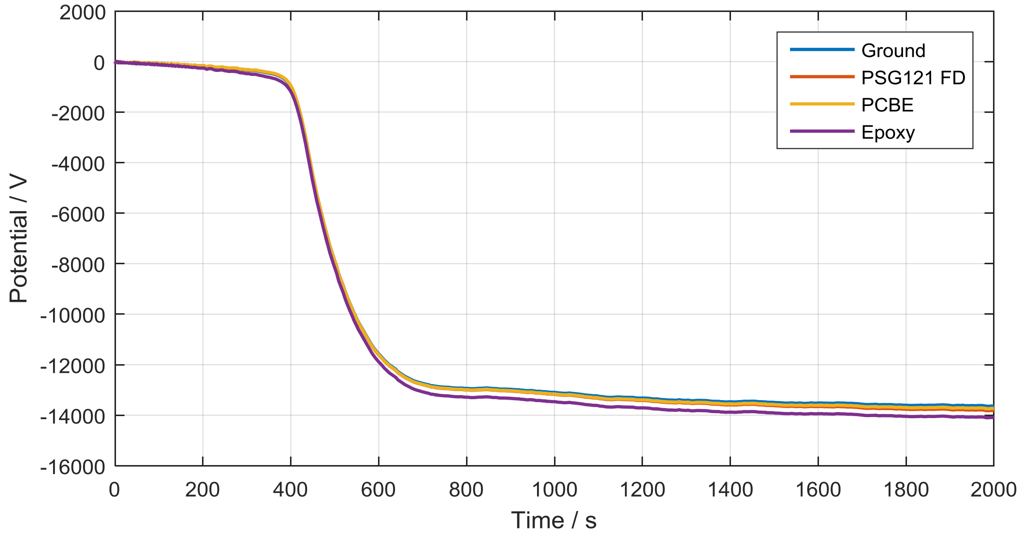
SPIS Settings

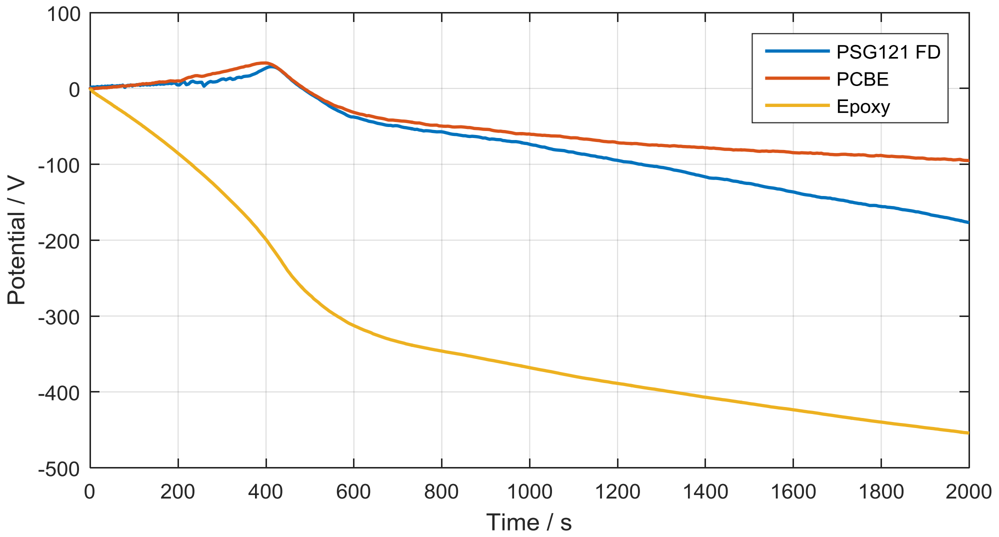
- Plasma modelling
  - PIC for the drifting populations
  - PIC backtracking for the high energy populations without drift
    - PIC for volume densities with backtracking for currents to the satellite
- Surface Interactions
  - Eclipse conditions are simulated -> no photoemission
  - SEE by electrons and ions is activated
  - Secondary particle dynamics is modelled using the PIC model
    - Temperature of secondary electrons has been set to 2 eV (SPIS default value)
- Satellite Capacitance is set to 1 µF
- Total simulation time is set for each case individually in order to reach an equilibrium if possible (depending also on total CPU time)
- Plasma drift velocity set perpendicular to the front surface of the SA
  - Considered worst case for the most critical element which is the SA rear side



Simulation Results – Ganymede Maxwellian Auroral Plasma

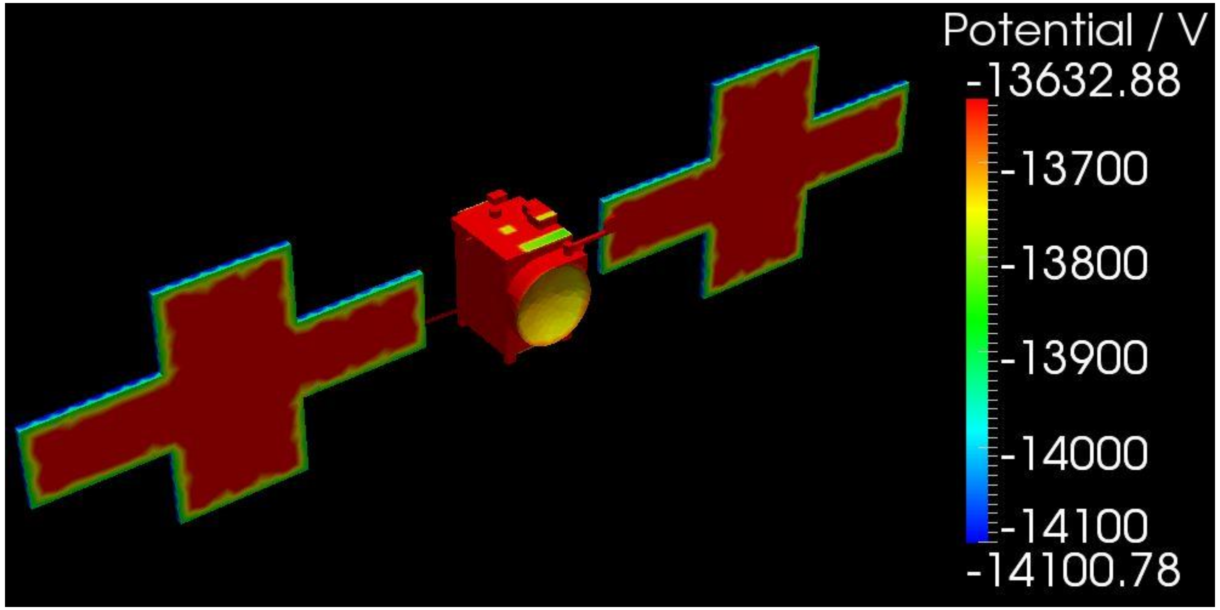
- Potential Evolution can be divided into 2 major parts
  - First 400 s with a surface potential greater than –1000 V
    - Strong SEE from the intermediate electron component with energy of 1000 eV slows the charging by the auroral electrons
  - After 400 s when the satellite potentials approach –1000 V
    - Energy of the intermediate electrons reaching the satellite is reduced below the 1st crossover point of the SEE yield and part of the electrons are repelled by the negative potential
    - Charging speed is then drastically increased until the SEE by the protons, ion collection, backscattering and SEE of the auroral electrons compensates the incoming electron flux
- Final differential charging reaches values clearly violating the 1 V requirement on the identified critical surfaces

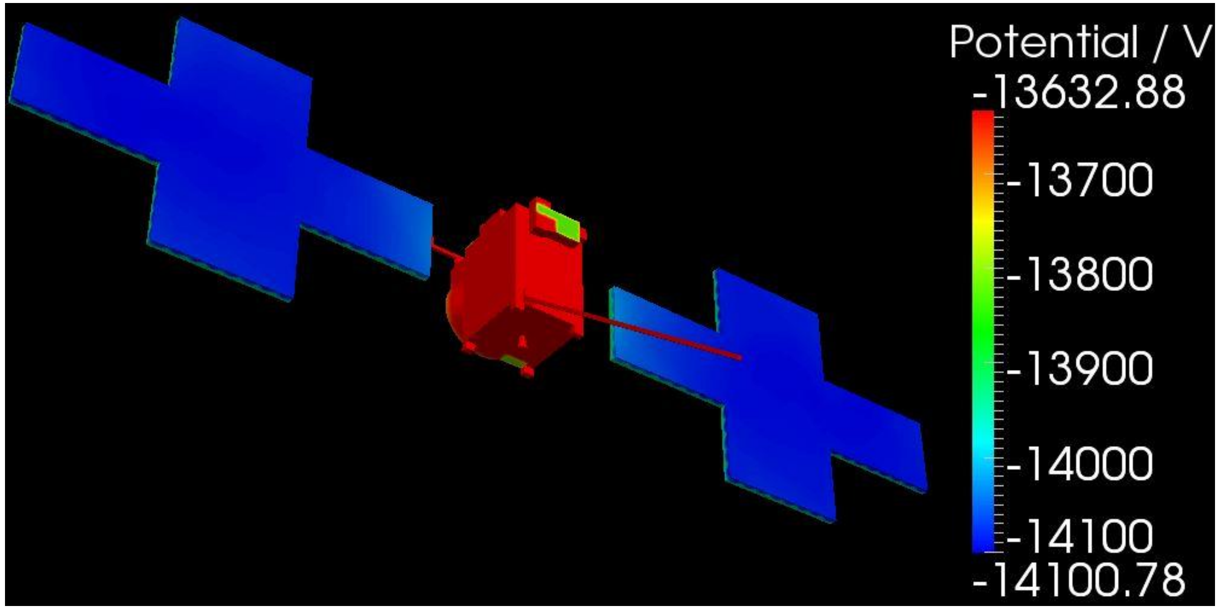




Simulation Results – Ganymede Maxwellian Auroral

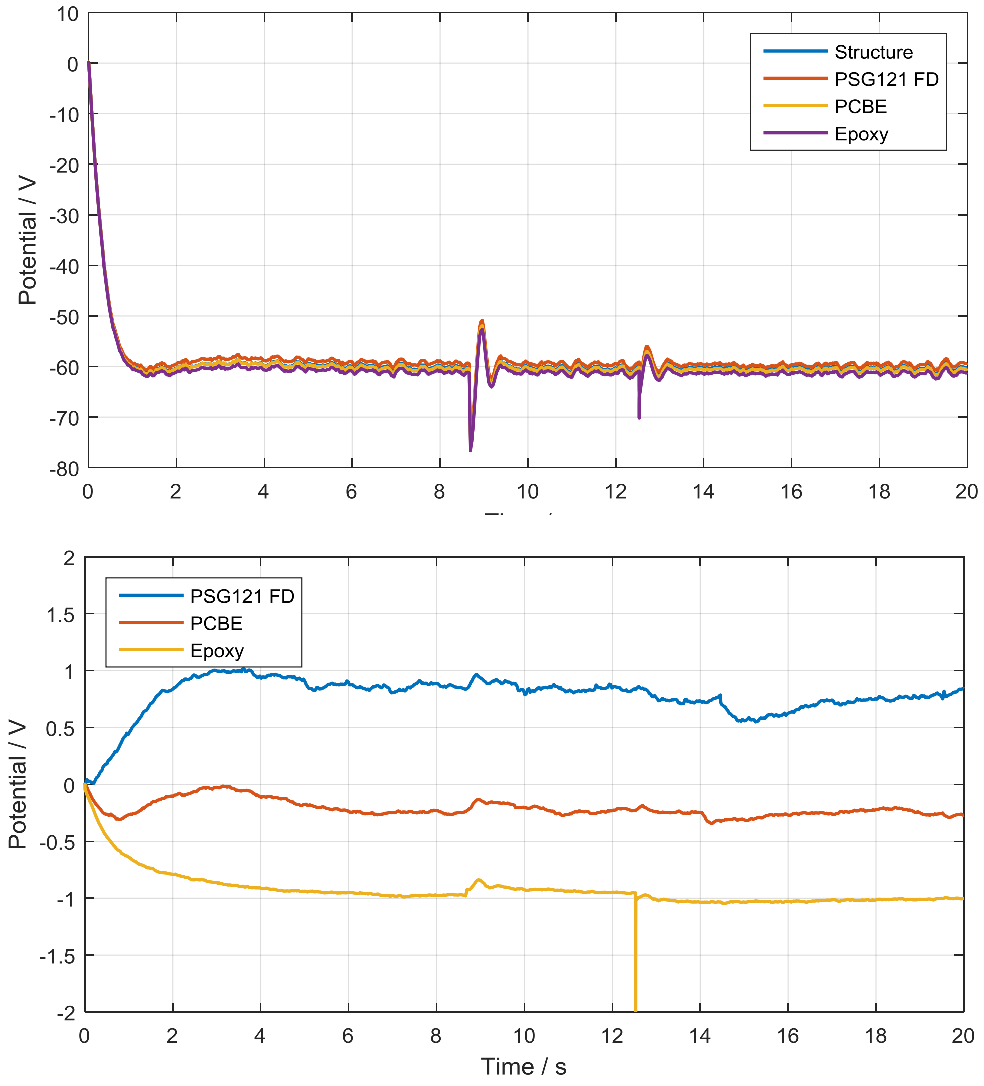
- Surface Potential distribution after 2000 s





Simulation Results – Ganymede Kappa Auroral

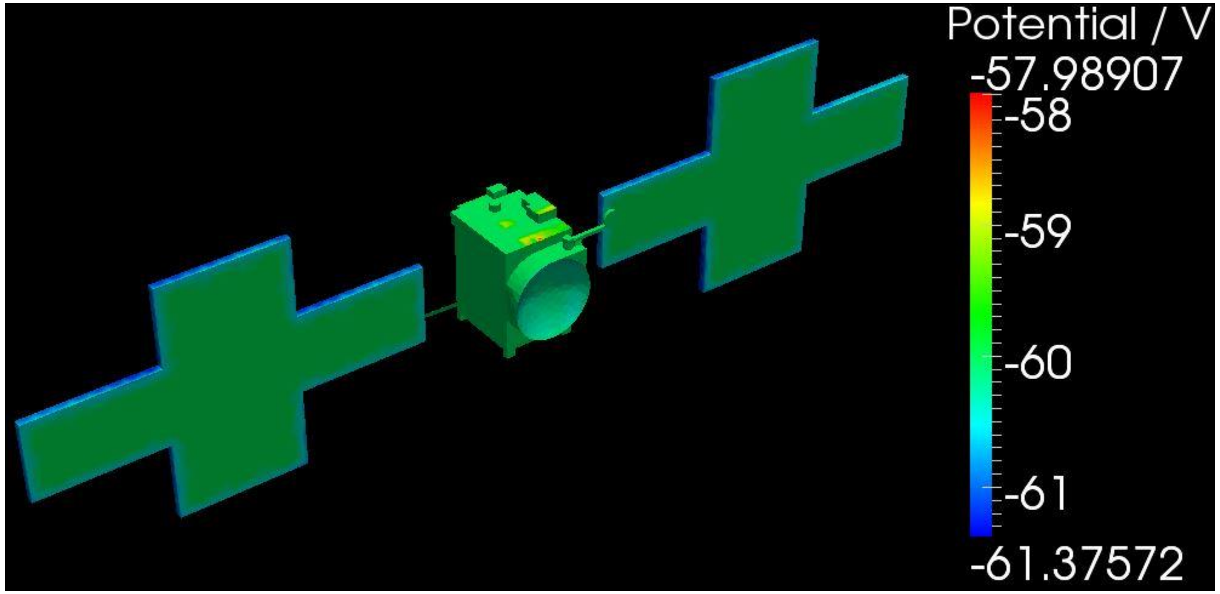
- Moderate absolute charging in this environment
  - Intermediate as well as Kappa component of the plasma are producing strong SEE
  - Low energy electrons along with the tail of the Kappa distribution lead to the moderate negative charging
- Differential potentials are very small, but the critical materials are still very close to the requirement

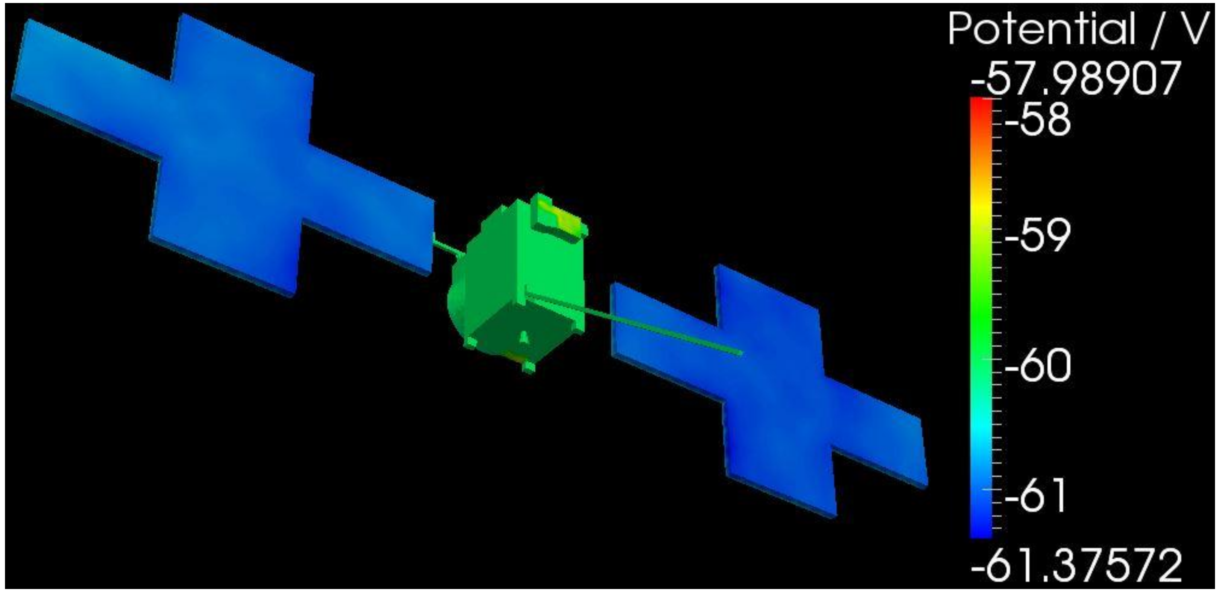


AIRBUS

Simulation Results – Ganymede Kappa Auroral

- Surface Potential distribution after 20 s

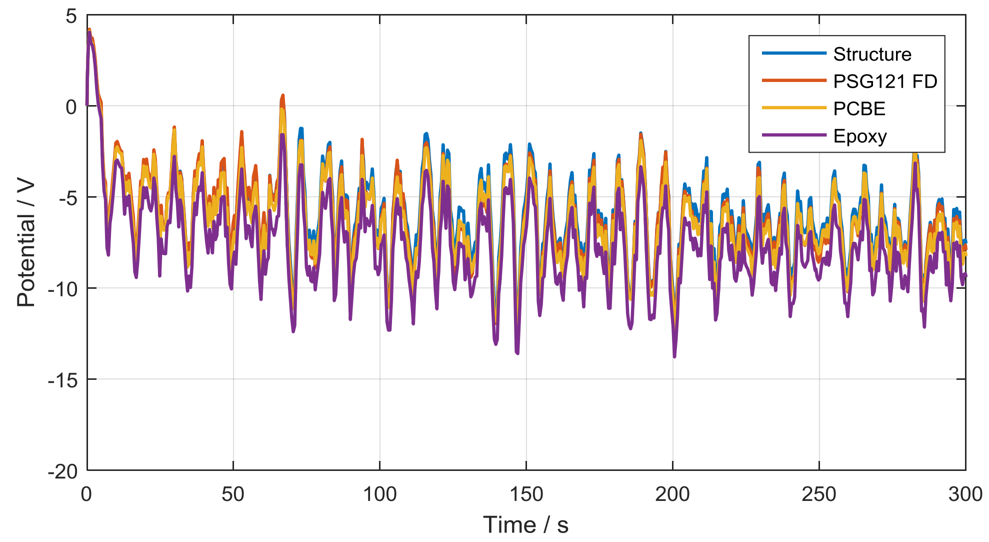


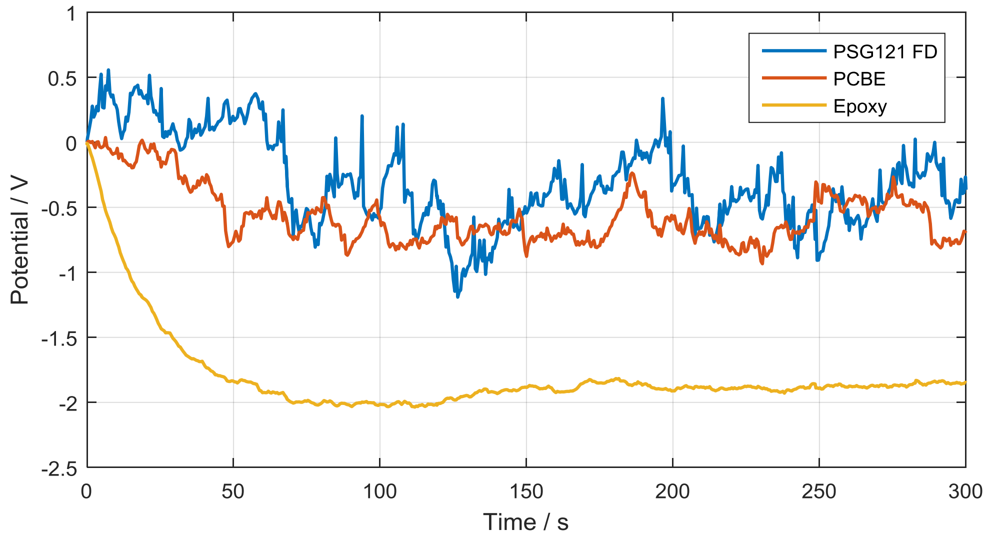


AIRBUS

Simulation Results – Ganymede Kappa Auroral

- Moderate absolute charging in this environment
  - Intermediate as well as Kappa component of the plasma are producing strong SEE
  - Low energy electrons along with the tail of the Kappa distribution lead to the moderate negative charging
- Differential potential on the paints is close to the requirement
- Rear side of the SA with bare Epoxy is violating the 1 V threshold

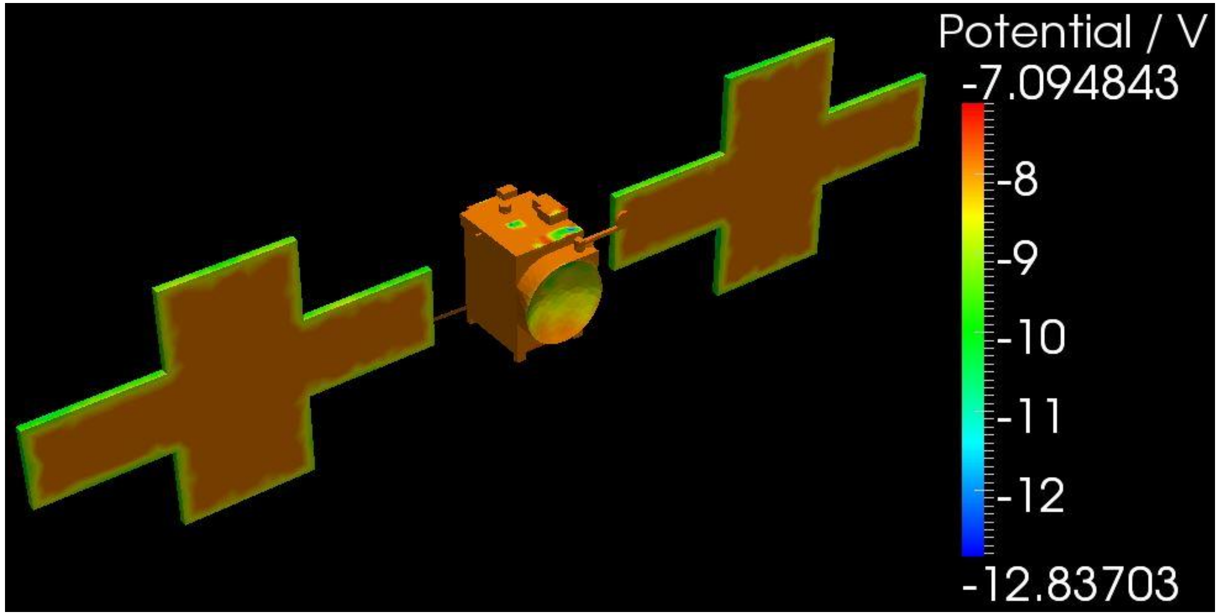


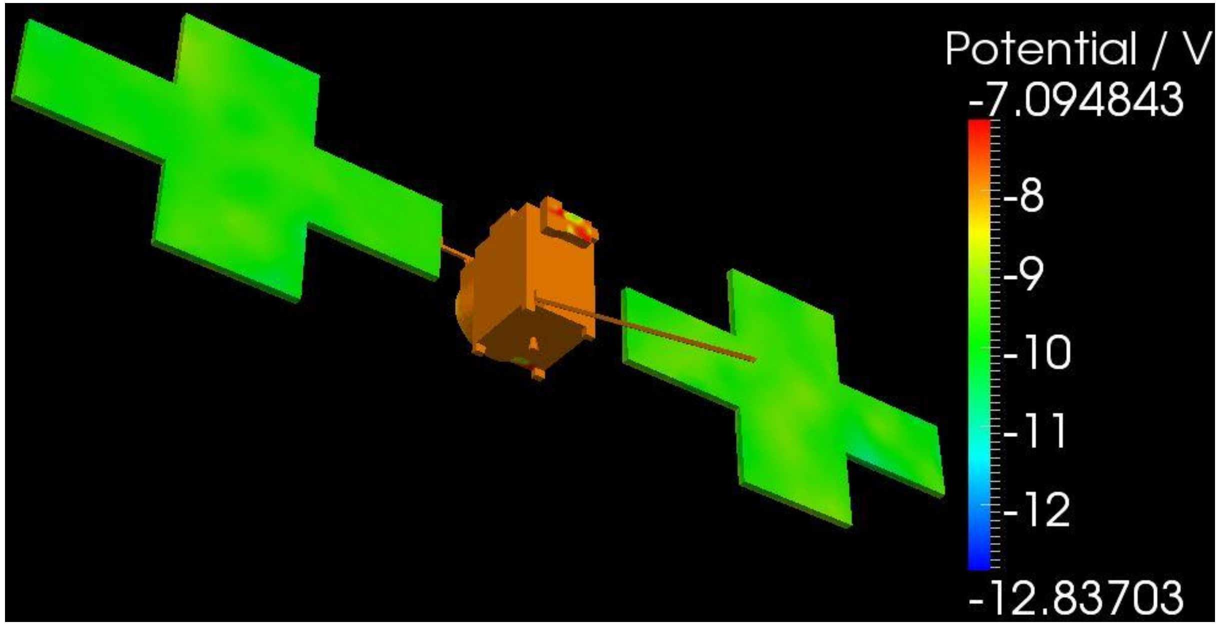


AIRBUS

Simulation Results – Ganymede Kappa Auroral

- Surface Potential distribution after 300 s





Conclusions – JUICE Satellite Design

- For the worst case definition around Ganymede the current baseline materials are not perfectly suited to meet the differential charging requirements
- In the other cases the requirements may also be difficult to reach
- Critical elements and surface materials are identified by the 3D simulations
- Alternatives in the design / material choices are currently investigated at system level to improve the charging behaviour
  - Samples of the SA panels will be tested to see the impact of the remaining Epoxy layer
    - Surface resistivity measurements performed at SA panel supplier are not representative
    - Design changes if the tests are not successful are already being investigated
  - HGA supplier is also planning tests for the coating to guarantee compliance to the requirements
    - Outcome for suitability of PCBE paint is questionable since the paint has already been ruled out for SOLO which has similar requirememts
  - Alternatives for the high temperature MLI and radiators are already selected
    - Appropriate properties have to be confirmed by representative tests

Conclusions – SPIS Feedback

- Material Properties
  - Datasheet values and supplier information have to be treated with extreme care
  - Can an European material property database be established?
    - Database with material parameter measurements performed in agreed and representative manner

- SPIS feedback
  - Circuit solver and automatic time step control
    - In my opinion one of the weak spots in SPIS
    - For complicated geometries / environments very annoying behaviour can be observed
      - Crashes: Software freezes at a certain time step and does not progress further
      - Discontinuities: surface potentials are “jumping” from one time step to the next by large amounts
      - Efficiency: For complex models the circuit solver currently is the least efficient part of the numerics with the longest CPU time

➢ some future developments should also aim at an improvement of the circuit solver to increase the speed and robustness of this part

Thank you