Charging simulations for a LEO Satellite with SPIS using different environmental inputs

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Introduction

- Powerful 3D tools for the analysis of charging and plasma interactions are available e.g. SPIS, Nascap2k, MUSCAT, Coulomb-2

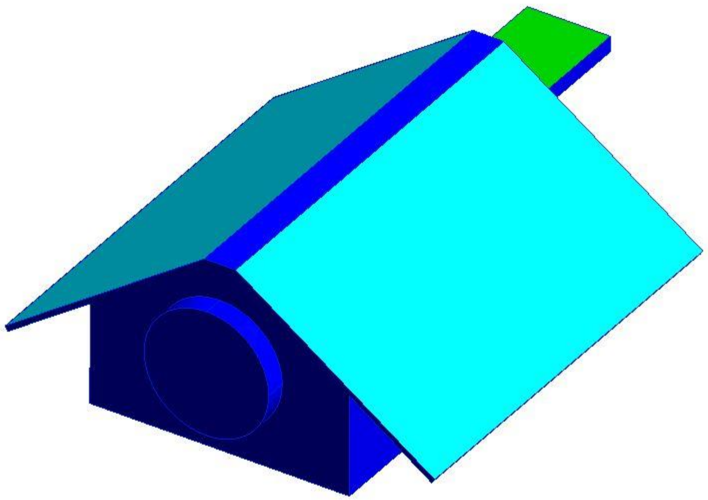
- Inputs to the analysis are very important and have to be focused
  - Material properties
  - Environment Definition for LEO auroral plasma -> big diversity of definitions to be found
    - SPENVIS tool
    - ECSS standard
    - Analysis of DMSP satellites

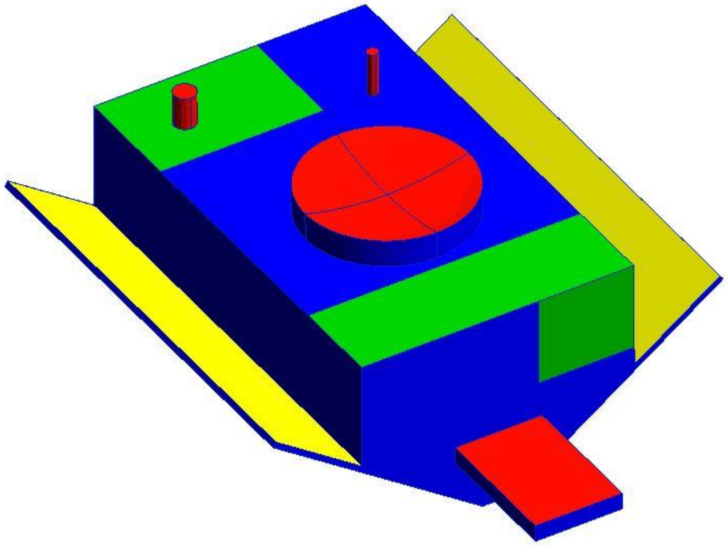
- Application of the different environmental inputs to SPIS simulations of a LEO satellite with body mounted SA
  - ➢ Show the high diversity of possible results
  - ➢ Create a basis for the discussion in the coming update of European charging standards

Modelling of the Satellite for the SPIS simulation

- Geometrical Model and Material distribution

Color	Description	SPIS Material
Yellow	Deployable SA rear; Epoxy resin on bare CFRK	Epoxy
Blue	Thermal Control MLI; Kapton	Kapton; 50 µm
Green	Radiators; Teflon SSM tapes	Teflon SSM Tapes; 125 µm
Red	Antennas	White Paint PSG121
Cyan	SA front	CERS





Modelling of the Satellite for the SPIS simulation

- SPIS basic simulation settings
  - All simulations are in eclipse
  - Electrons modelled with the Fluid approach in SPIS
  - Ions are modelled with the PIC model which allows to adress the SC velocity
  - SEE by electrons and ions is activated
  - Calculation is performed up to a total simulation time of 60 s

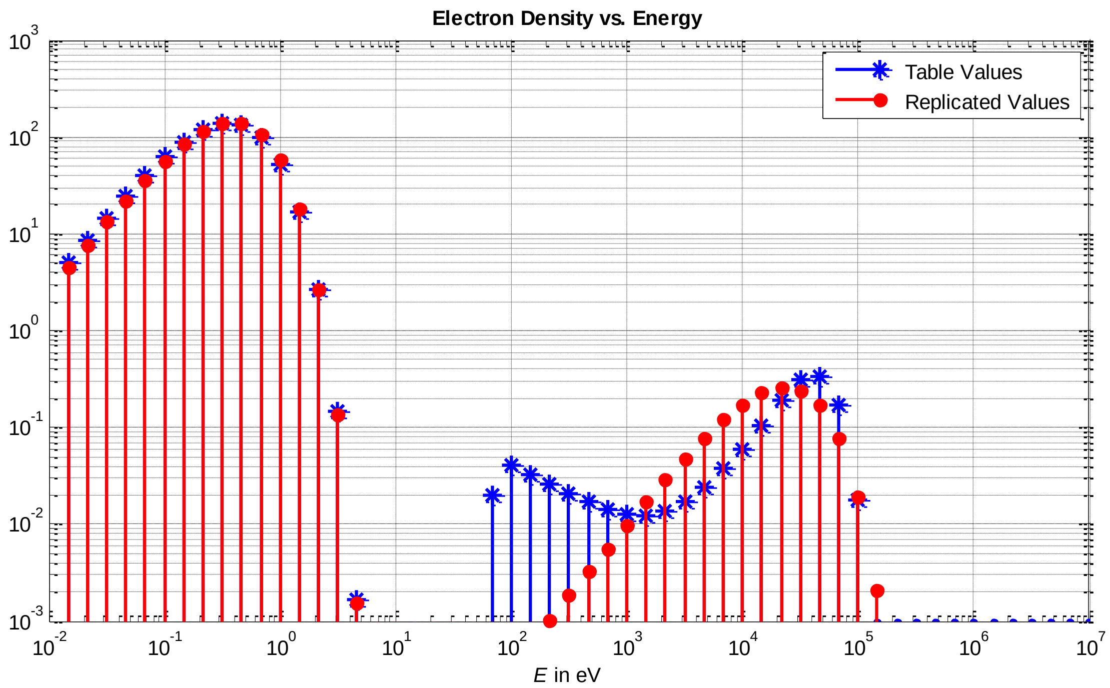
Environment Definition

- The simulations will be performed in four different environments given in literature or charging tools
  - SPENVIS environment “Cold single Maxwellian and Fontheim electrons” (SPENVIS Fontheim)
  - SPENVIS Fontheim environment with ECSS 10-04C cold background density
  - ECSS 10-04C auroral plasma definition
  - ECSS 10-04C auroral high energy electron definition with background density from David L. Cooke (AFRL-VS-TR-20001578)

- For LEO simulations using SPIS it is beneficial to use a Maxwellian distribution for the electrons
  - Allows for the usage of the fluid model for the electrons which saves simulation time and memory
  - Fitting has to be performed for some of the environmental inputs

Environment Definition – SPENVIS Fontheim

- The particle distribution in SPENVIS is given as a discrete particle spectrum
  - This distribution has to be fitted by Maxwellian distributions to be used in SPIS
- Baseline for the fitting is to keep the total charge density constant
  - This has the constraint that in the fitted environment there may be particles at energies where nothing has been specified in the SPENVIS plots



Population	Density in cm^{-3}	Energy in eV
Electrons1	809.9	0.2156
Electrons2	1.482	12940
Ions1	812.4	0.2156

For the simulations with the ECSS background the density of the cold plasma is set to 125 cm^{-3} with a temperature of 0.2 eV

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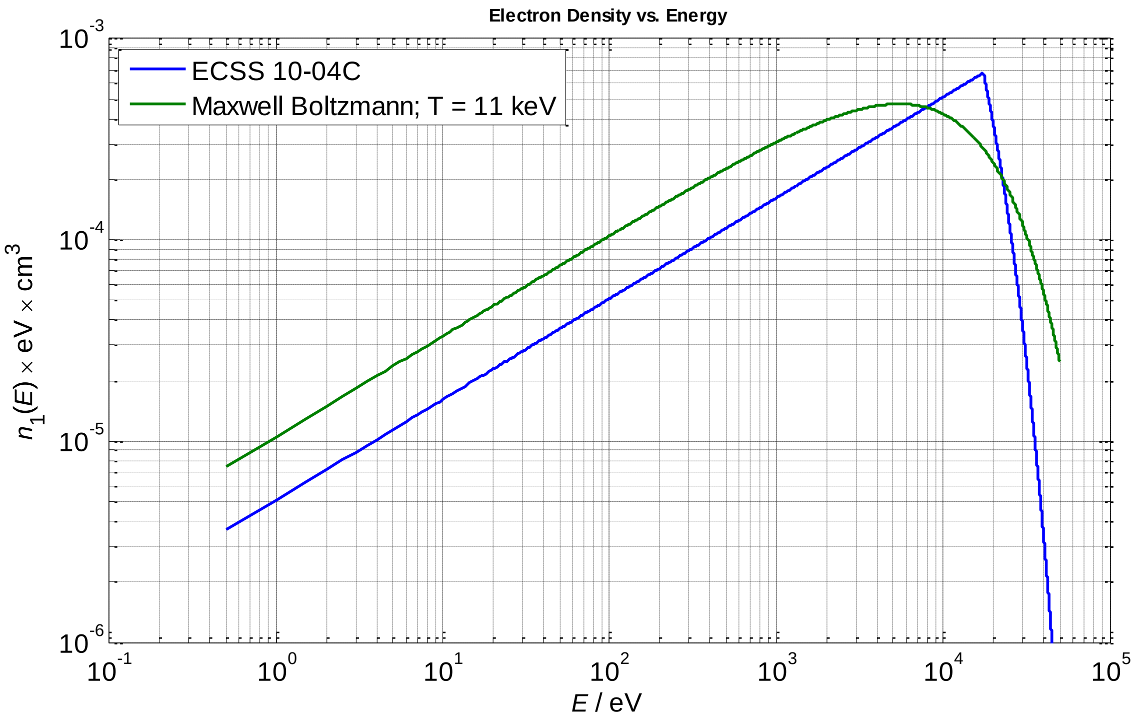
Environment Definition – ECSS & Environment used by Cooke

- Auroral electron particle density according to ECSS-10-04C is defined as

$$f(v) = 3.9 \cdot 10^{-18} \ \ \mathrm{s}^3\mathrm{m}^{-6} \qquad \text{, for} \quad E \leq 17.44\ \mathrm{keV}$$

$$f(v) = \frac{N_0 \cdot {m_e}^{3/2} \cdot \exp(-\frac{E-E_0}{k \cdot T_0})}{(2\pi \cdot k \cdot T_0)^{3/2}} \qquad \text{, for} \quad E > 17.44\ \mathrm{keV}$$

$$with:\ N_0 = 1.13 \cdot 10^6\ \mathrm{m}^{-3}\ ;\ k \cdot T_0 = 3.96\ \mathrm{keV}\ ;\ E_0 = 17.44\ \mathrm{keV}$$



Population	Density in cm^{-3}	Energy in eV
Electrons1	125	0.2
Electrons2	10.78	11000
Ions1	125	0.2

For the simulations with the environment by Cooke the density of the cold plasma is set to 3000 cm^{-3}

Environment Definition – Qualitative Assessment

- Already a qualitative inspection of the different environments suggest a big diversity of the to be expected charging results
  - ECSS environment has a remarkably increased high energy particle density as well as lower cold background density than the SPENVIS Fontheim definition
  - ECSS defines a strongly reduced background particle density in comparison to the values used by Cooke for the DMSP analysis with the Polar code

➢ strong differences in the results are to be expected

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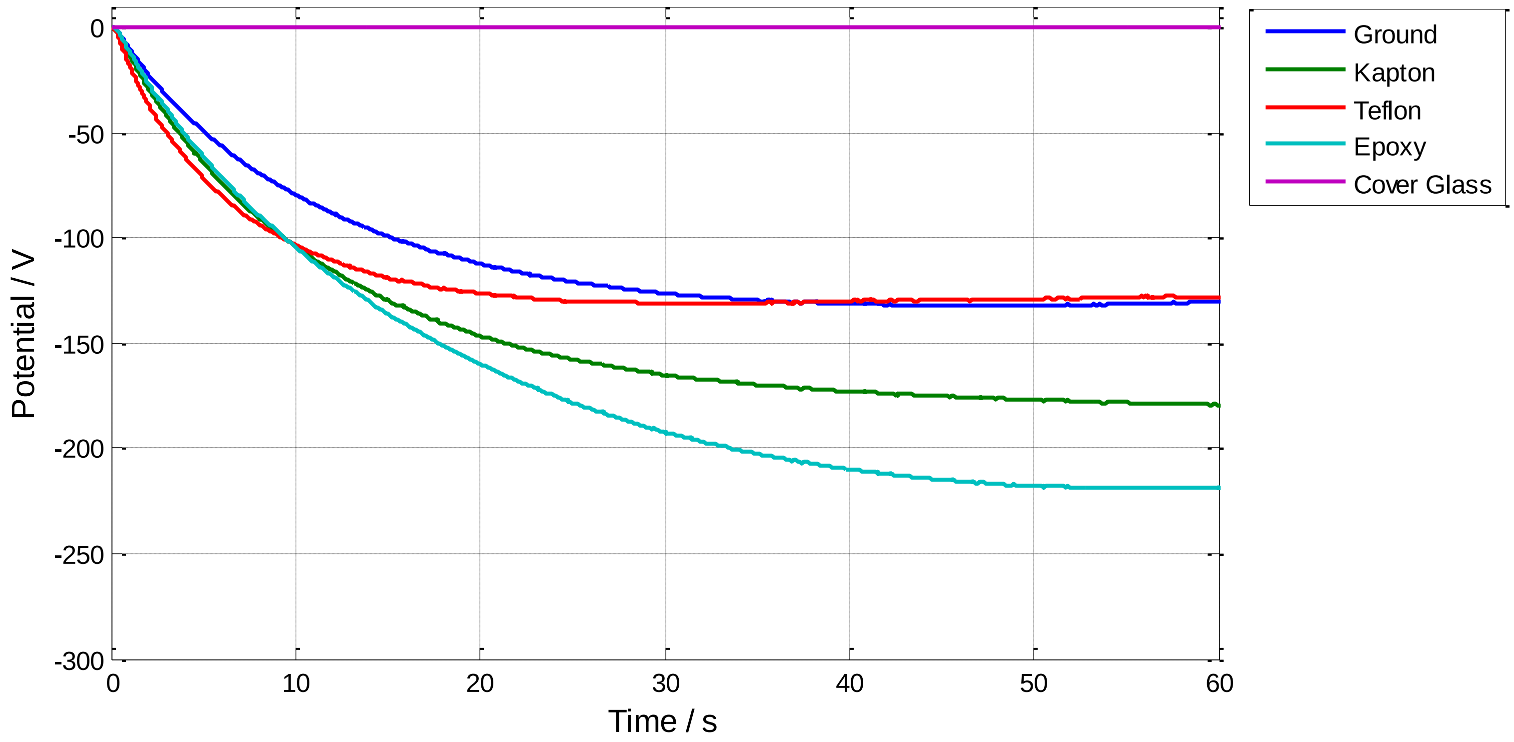
Simulation Results – SPENVIS Fontheim Environment

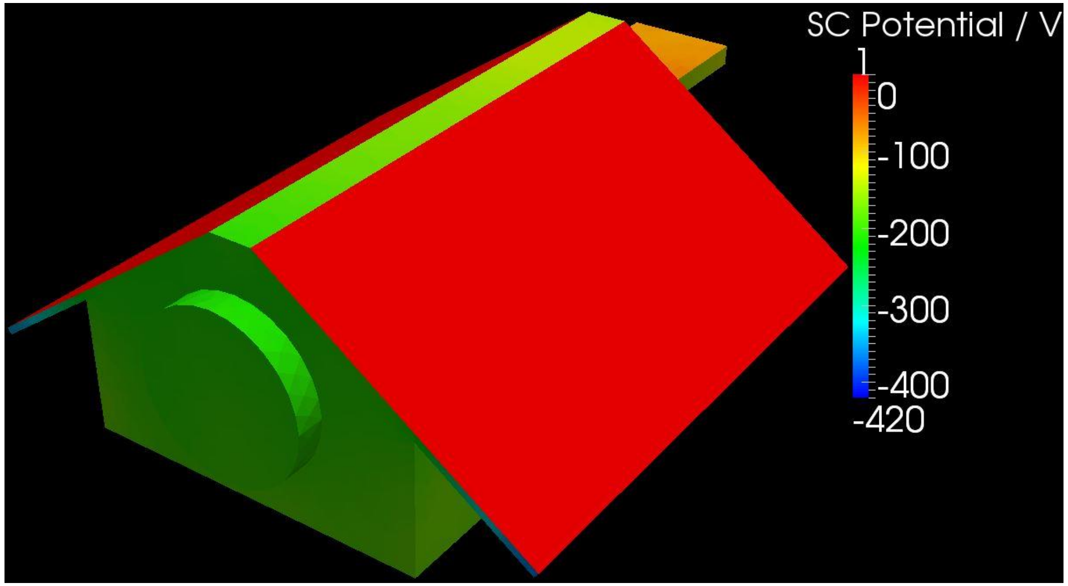
- Time dependent surface potentials show moderate charging levels on the satellite
  - ➢IPG between structure and SA cover glasses of about 130 V

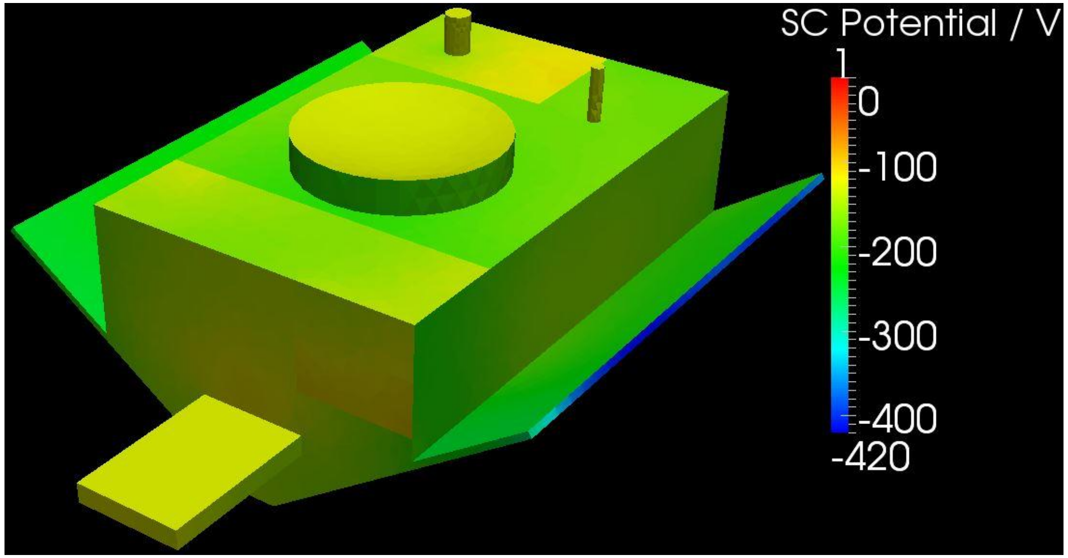


Simulation Results – SPENVIS Fontheim Environment

- Spatial surface potential distribution
  - ➢Minimum potential of about -420 V on the SA edges
  - ➢MLI at the wake parts of the structure at about -250 V
  - ➢No violation of ECSS 20-06C requirements due to DPGs
  - ➢Slight violation of the requirement regarding IPG of ECSS 20-06C

→ low risks for the satellite due to charging





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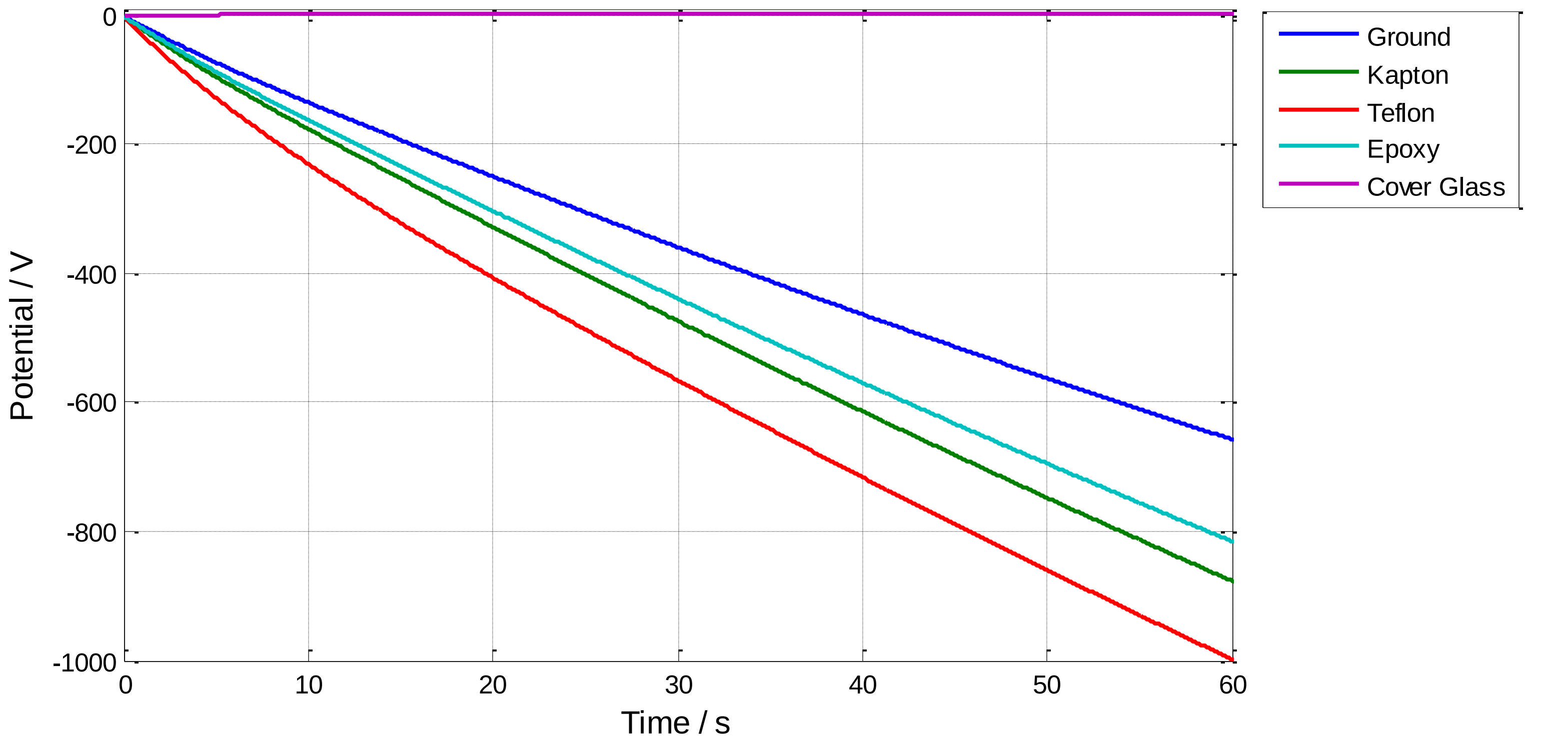
Simulation Results – SPENVIS Fontheim with ECSS cold background

- The reduced cold plasma density leads to increased negative charging since less cold ions for compensation are available
  - ➢IPG between structure and SA cover glasses rises to about 650 V
  - ➢Averaged surface potentials on the radiators are close to -1 kV



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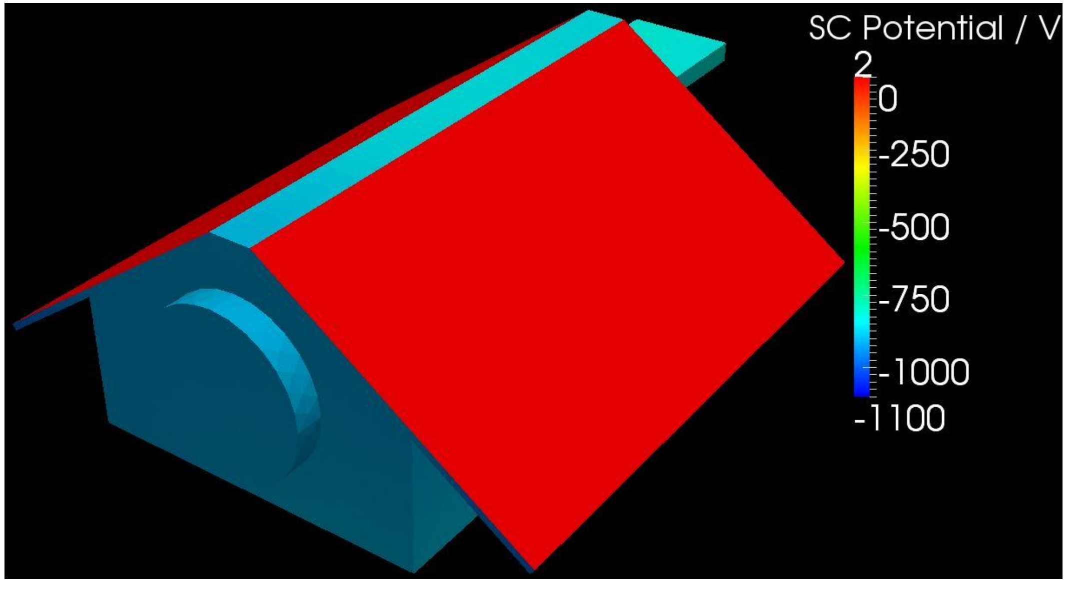
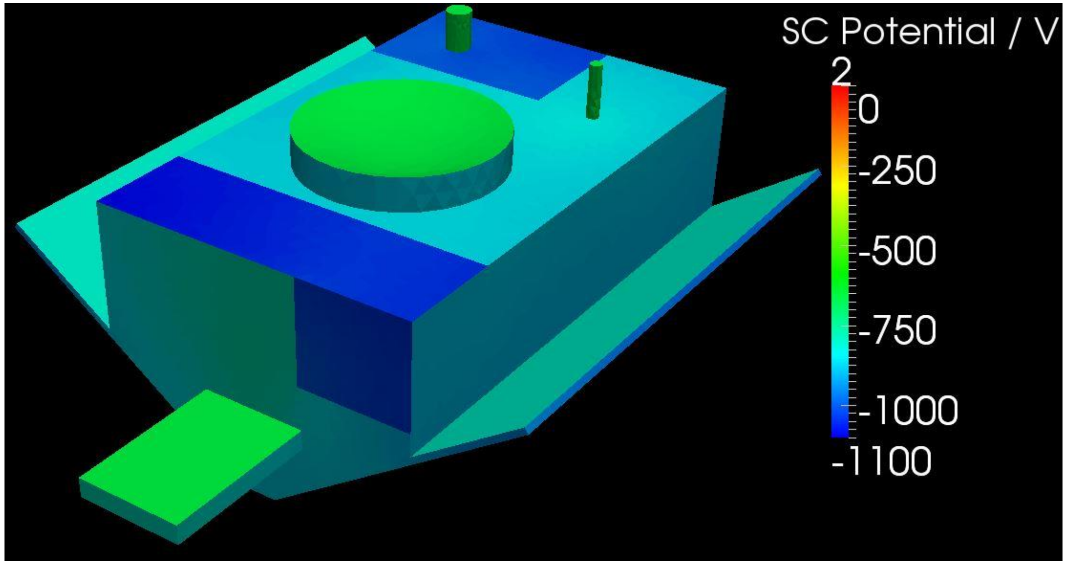
Simulation Results – SPENVIS Fontheim with ECSS cold background

- Spatial surface potential distribution
  - ➢Minimum potential of about -1100 V on the radiators
  - ➢MLI at the wake parts of the structure at about -850 V
  - ➢No violation of ECSS 20-06C requirements due to DPGs
  - ➢Violation of the requirement regarding IPG of ECSS 20-06C
  - ➢possibility for primary arcs on the SA

→ moderate risks for the satellite due to charging

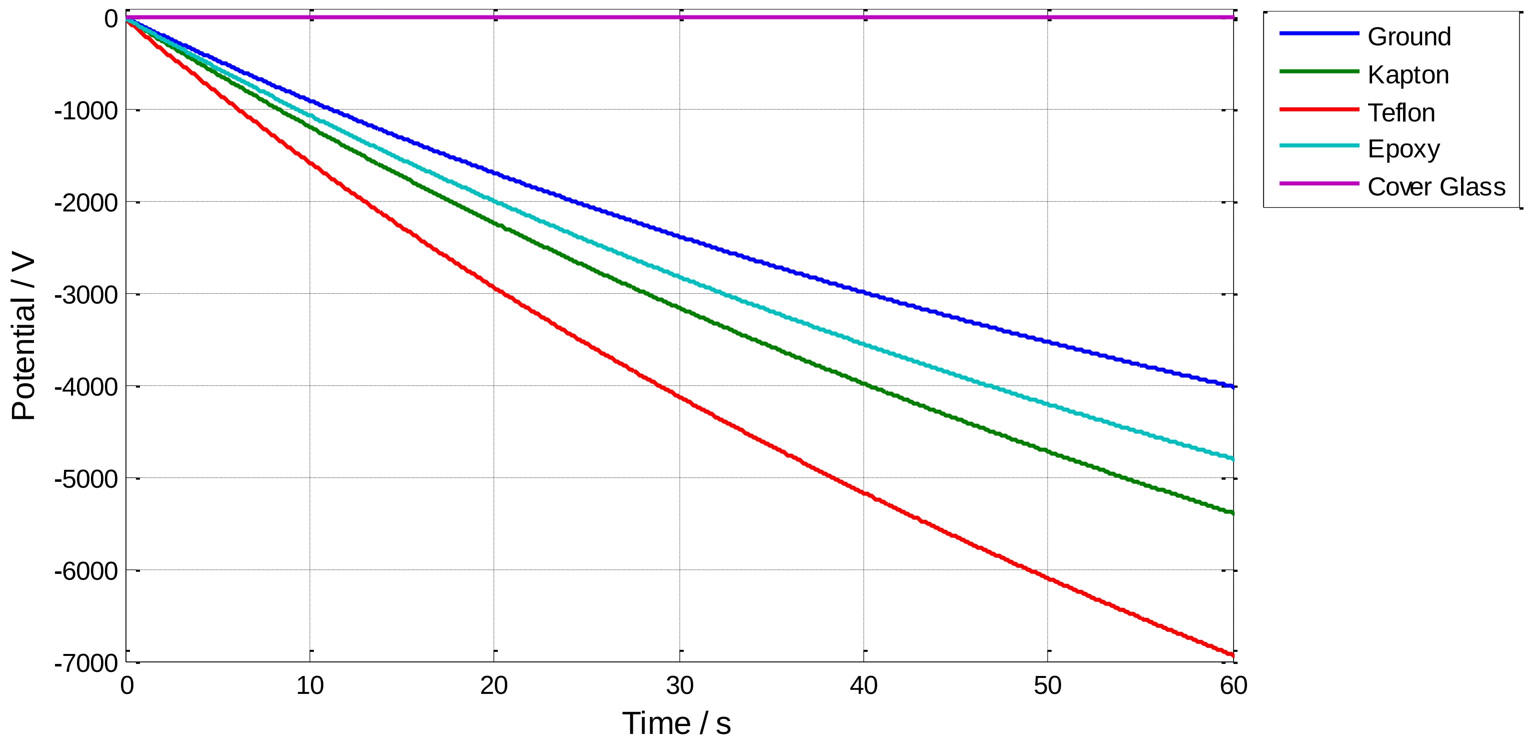
→ possible mitigation actions should be envisaged (e.g. use of ITO coating on radiators)





Simulation Results – ECSS environment

- Extreme negative charging of all surfaces except the cover glasses is observed in this environment
  - ➢IPG on the SA rises to about 4000 V
  - ➢Minimum averaged potentials on the radiators of -7000 V
  - ➢Averaged potentials of Kapton MLI at about -5300 V



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Simulation Results – ECSS Environment

- Spatial surface potential distribution

➢ Minimum potential of about -7300 V on the radiators

➢ MLI at the wake parts of the structure at about -5500 V

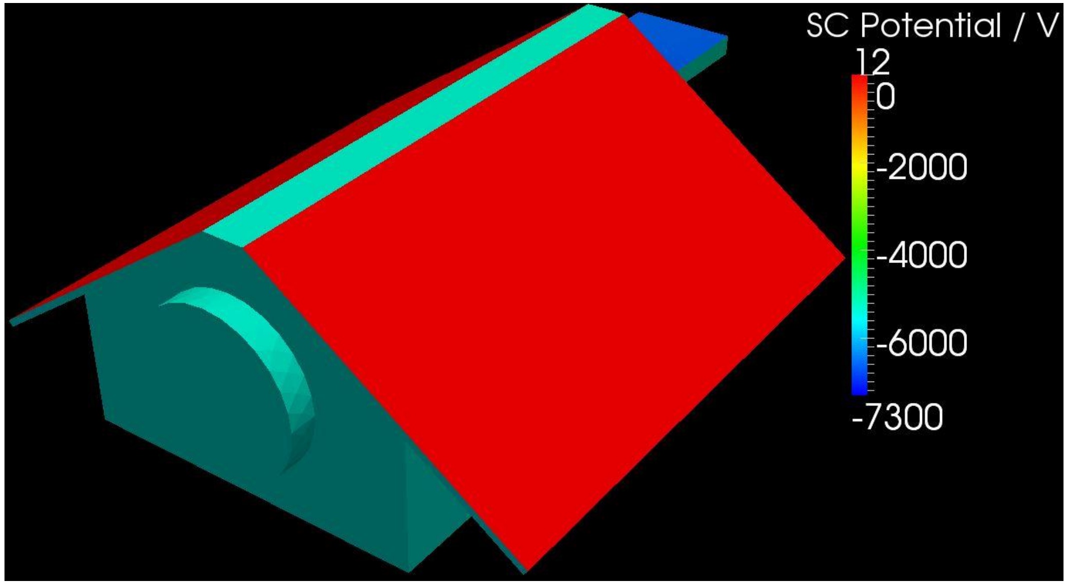
➢ Violation of ECSS 20-06C requirements due to DPGs both on the radiators and the Kapton MLI

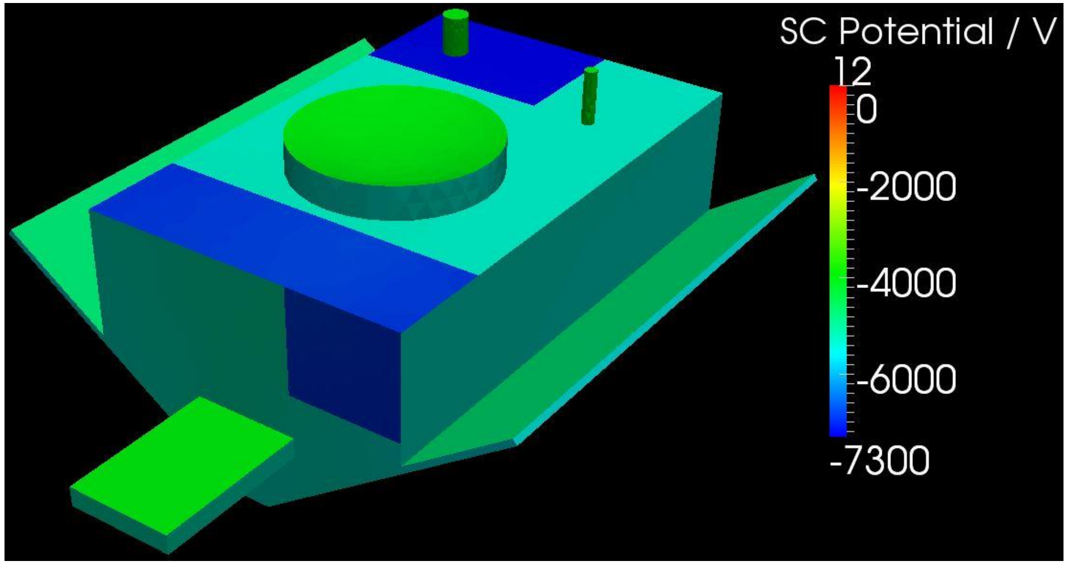
➢ Violation of the requirement regarding IPG of ECSS 20-06C

➢ possibility for primary arcs on the SA and arcs on the satellite body

→ high risks for the satellite due to charging

→ mitigation still effective/possible?





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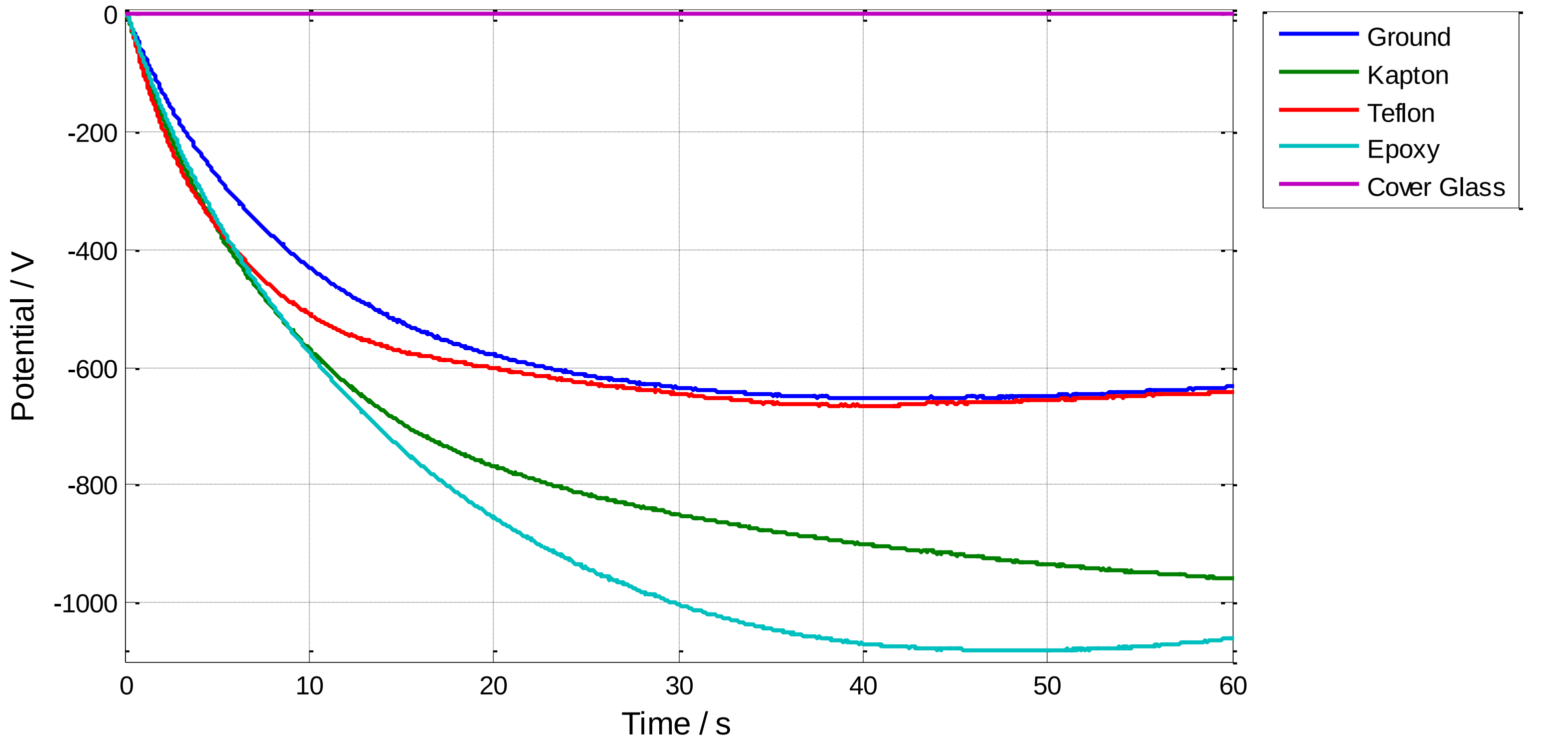
Simulation Results – ECSS with Cooke cold density

- The increased background particle density leads to a reduction of the negative potentials
  - ➢IPG on the SA at about 630 V
  - ➢Minimum averaged potentials on the radiators of -1100 V
  - ➢Averaged potentials of Kapton MLI at about -950 V



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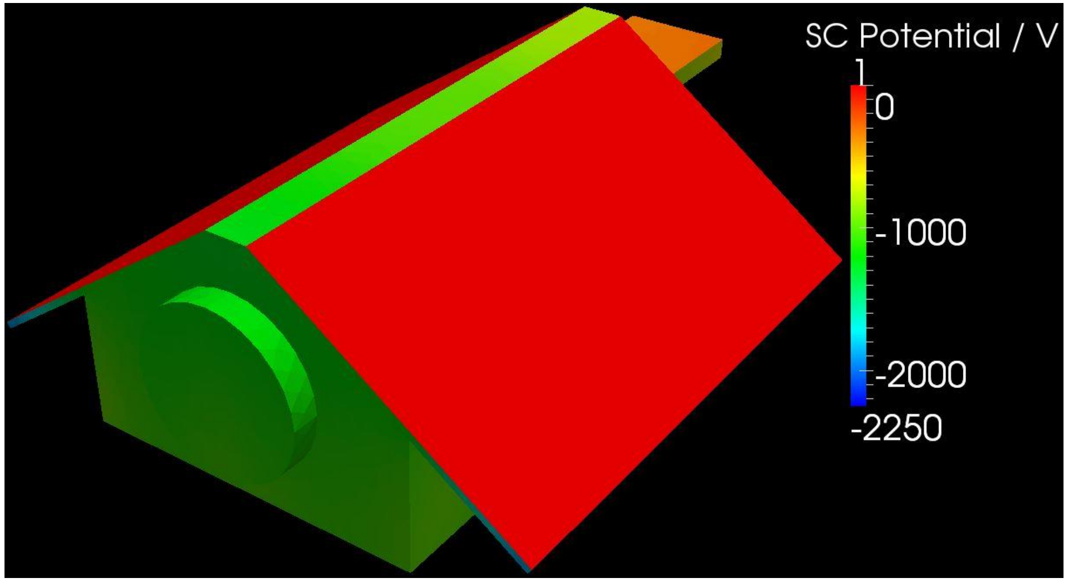
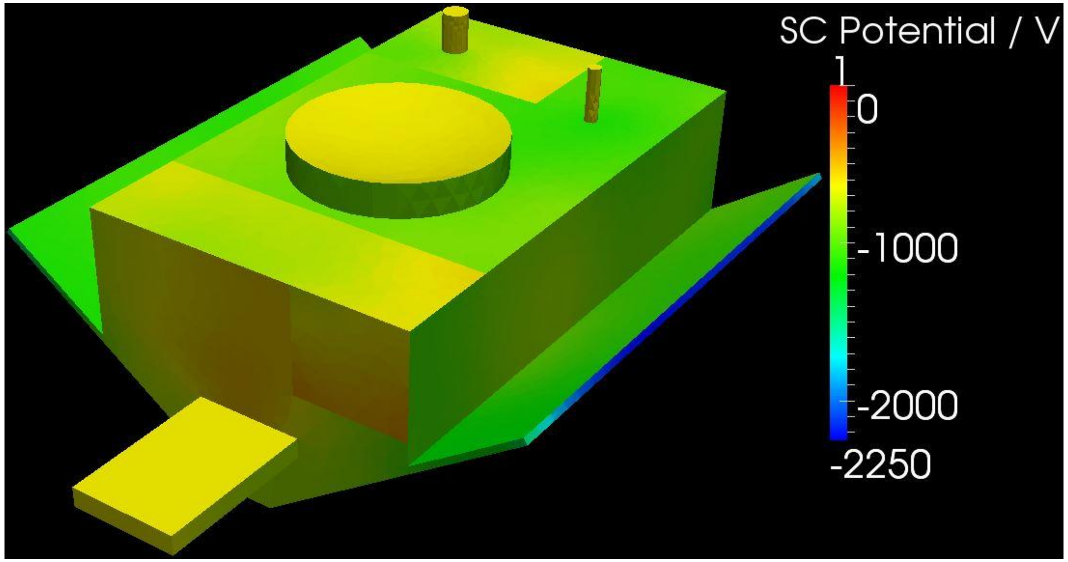
Simulation Results – ECSS with Cooke cold density

- Spatial surface potential distribution
  - ➢Minimum potential of about -2250 V on the edge of the SA
  - ➢MLI at the wake parts of the structure at about -1000 V
  - ➢Violation of ECSS 20-06C requirements due to DPGs only on the SA edges
  - ➢Violation of the requirement regarding IPG of ECSS 20-06C
  - ➢possibility for primary arcs on the SA

→ moderate risks for the satellite due to charging

→ mitigation has to be envisaged like ITO coatings on radiators





Summary and Conclusions

- 3D SPIS simulations of a LEO satellite in 4 different environments have been performed
  - ➢Strong differences in the results are observed
  - ➢Charging from uncritical to extremely severe potentials

- Strong diversity of definitions and results are considered critical from industrial point of view
  - ➢Mitigation measures vary strongly depending on the chosen environment input
  - ➢Combination of two worst cases for high energy electrons and low energy background plasma in current ECSS is questionable

➢Better characterization of the worst case auroral plasma in LEO is desirable

➢Consolidation of the environment specification in the update of ECSS standards is considered necessary

➢Environment definitions using Maxwell-Boltzmann distributions are appreciated