EarthCARE SPIS Charging Analysis

Christian Imhof

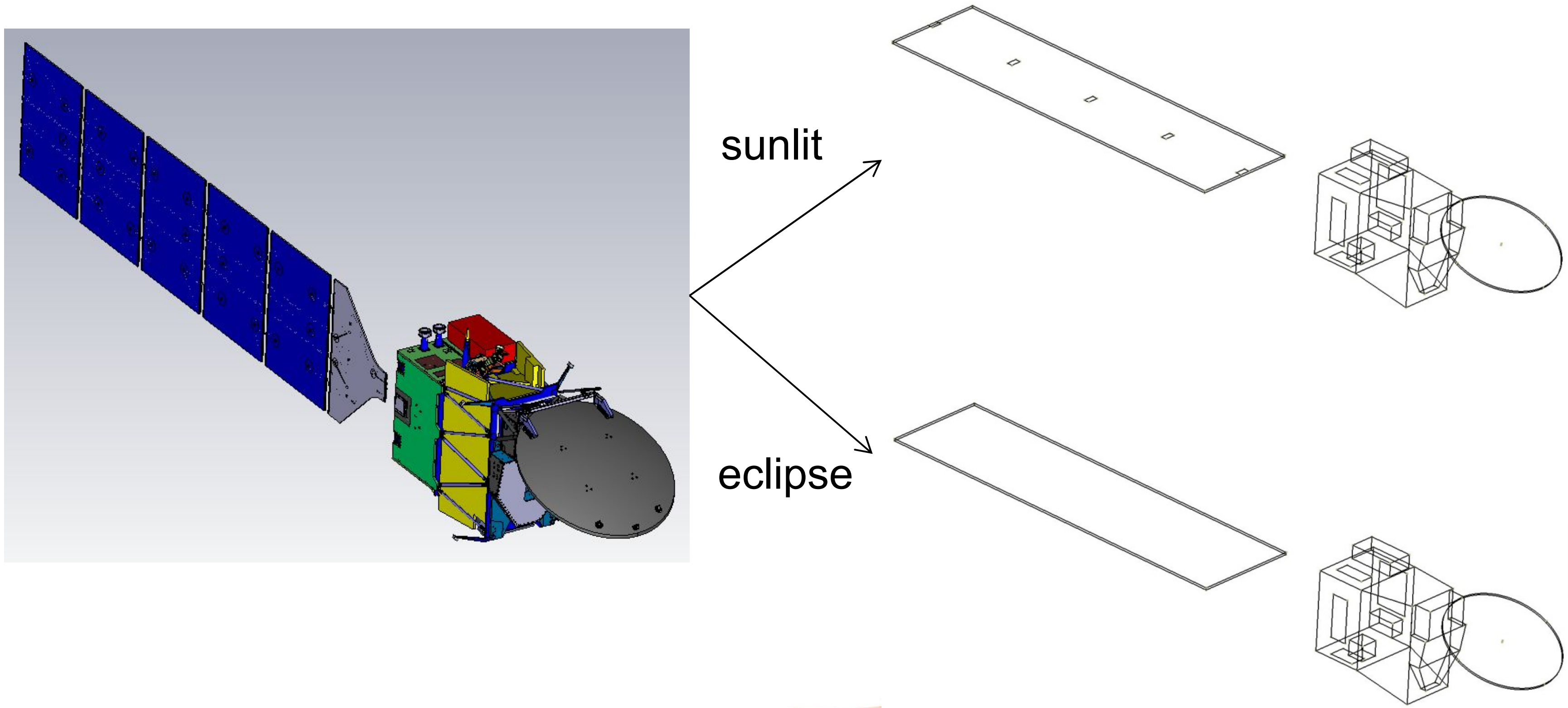
All the space you need

Outline

- Modelling of the Satellite
- Simulation Settings
- Simulation Results
- Conclusions

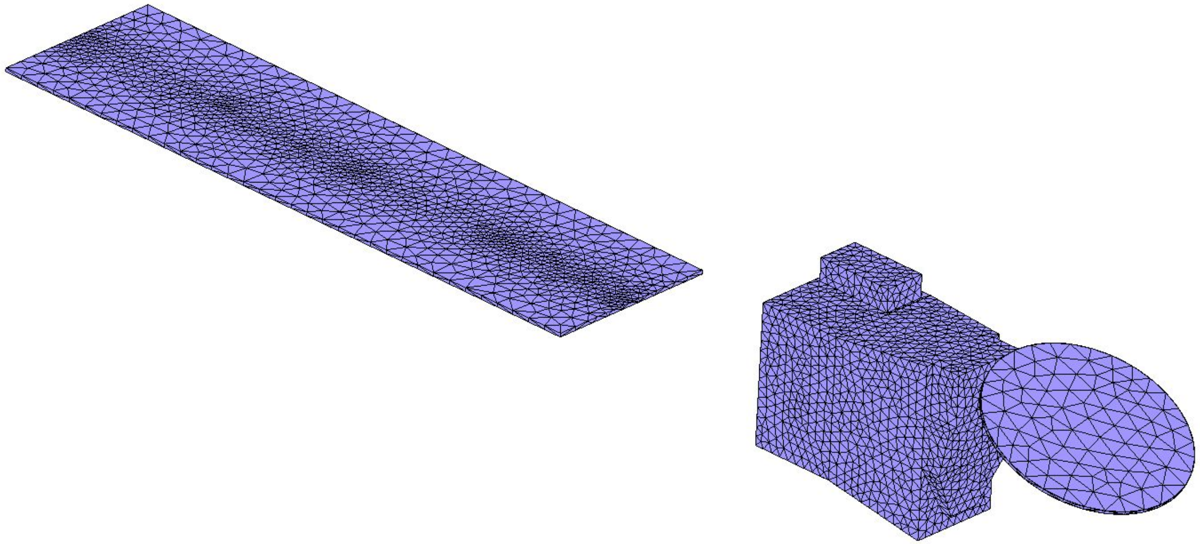
Modelling of the satellite

Trade off between detailled modelling and hardware / CPU time demands



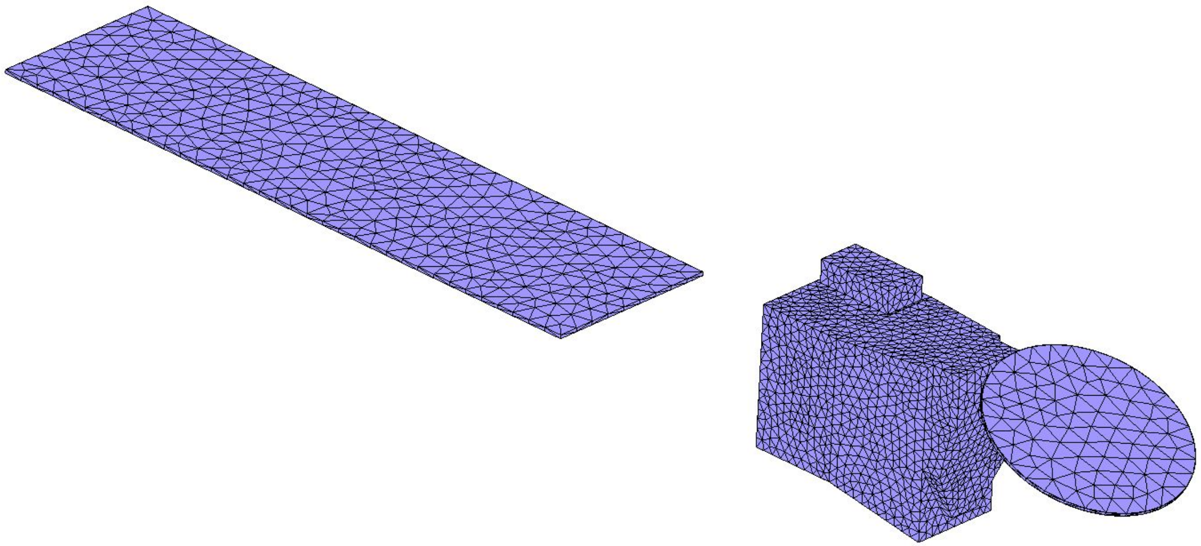
Modelling of the Satellite

- Meshing
  - Sunlit: ≈ 7530 surface cells
    ≈ 265.500 volume cells



Modelling of the Satellite

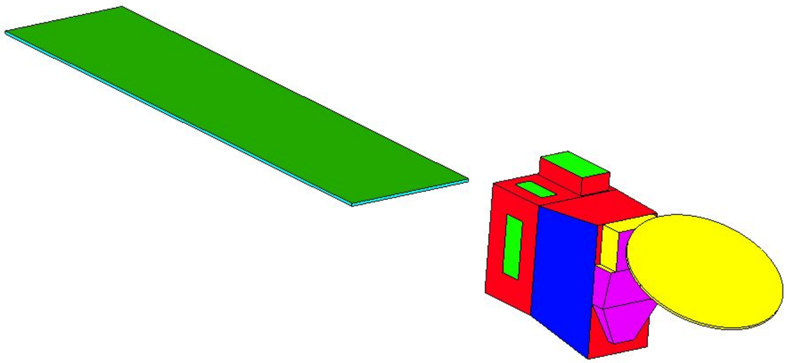
- Meshing
  - Eclipse: ≈ 5850 surface cells
    ≈ 250700 volume cells

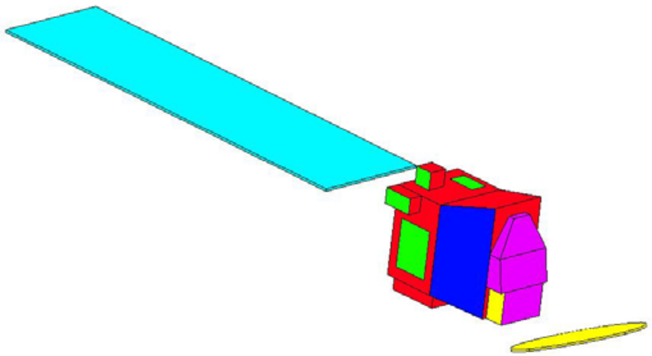


Modelling of the Satellite

- Material Distribution (Eclipse)

Colour	Description	SPIS Material	Node #
Light Green	Platform Radiators	ITO	0 (SC Ground)
Red	Betacloth MLI	Teflon	1
Dark Blue	ATLID Radiators	PSG120	2
Yellow	CPR MLI	Germanium	3
Purple	CPR Radiators	OSR	4
Cyan	SA Structure	PCB-Z	5
Dark Green	SA Cover Glass	CERS / CMG	6





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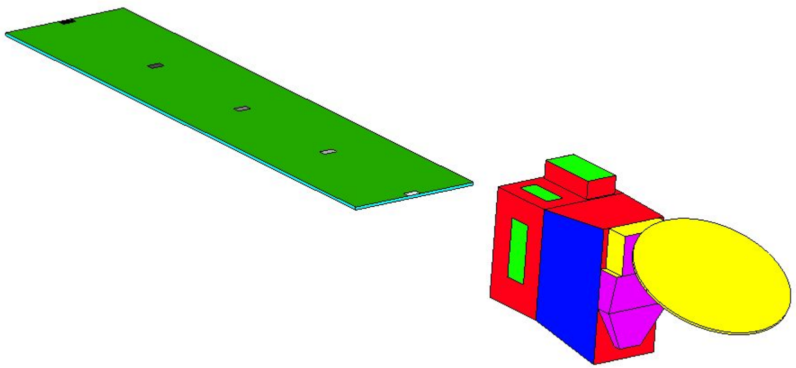
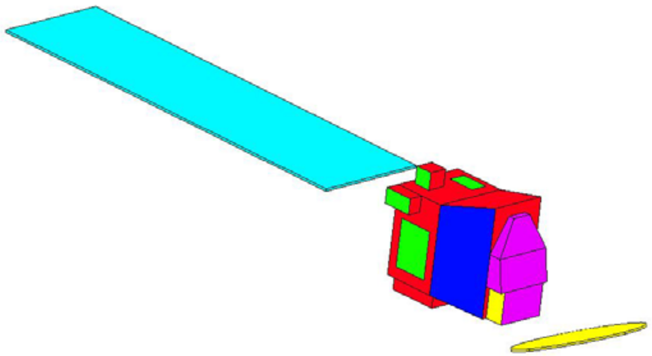
Cyan	SA Structure		PCB-Z	5
Dark Green	SA Cover Glass		CERS / CMG	6
White	Merged SA Space Exposed Conductive Areas	V_{bias} = 0 V	Silver	7
Light Gray		V_{bias} = 22.5 V	Silver	8
Medium Gray		V_{bias} = 45 V	Silver	9
Dark Gray		V_{bias} = 67.5 V	Silver	10
Black		V_{bias} = 90 V	Silver	11





Modelling of the Satellite

- ''New'' Material (not originally included in SPIS)
  - Germanium
    - Specific conductivity given as 2,1 S/m
      → using this value led to instabilities of the circuit solver
  - Solved by modelling Germanium as perfect conductor
    - Justification:

$$R = \frac{l}{\sigma \cdot A}$$, with *l* = 50 µm (thickness of the Germanium layer)

gives 23,8 µΩ * m^2

→ U = 2,38 µV for typical LEO current densities of 0,1 A / m^2

  - SEE yield of Ge chosen as 0,8; conservative approach

Modelling of the Satellite

- SA Cover Glass
  - CERS as in SPIS material database
    - Specific conductivity of 10^{-15} S/m
  - CMG Glass as specified by Dutch Space
    - Specific conductivity of $2,5*10^{-16}$ S/m
  - Influence of this Parameter will be assessed in the worst case simulations (Fontheim with eclipse)

Simulation Setup

- 393 km sun synchronous orbit with high inclination
  → passage of the auroral region as driver for worst case plasma environment

- Used Maxwellian Plasma Parameters

  - Quiet LEO environment

Population	Density in cm^{-3}	Energy in eV
Electrons	10^5	0,2
Ions (O^+)	10^5	0,1

  - Auroral Plasma environment; based on SPENVIS Fontheim definition

Population	Density in cm^{-3}	Energy in eV
Electrons 1	809,9	0,2156
Electrons 2	1,482	12940
Ions (O^+)	811,3	0,2156

Simulation Setup

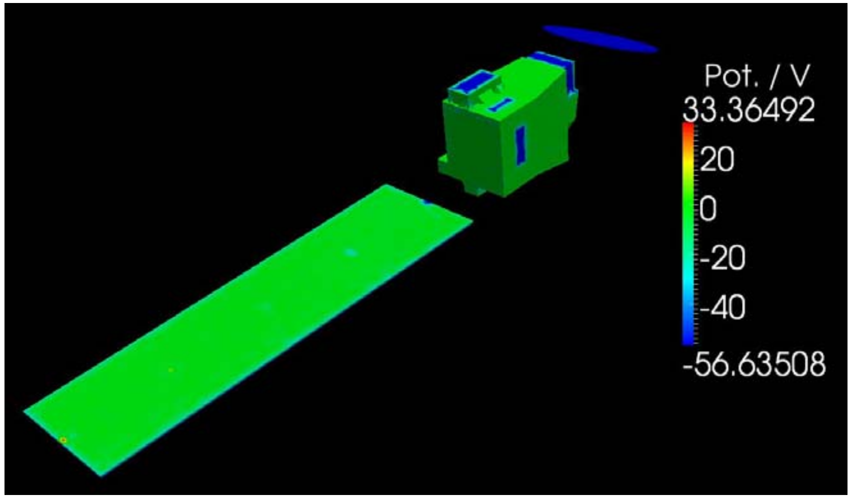
- Global Settings of the simulation
  - Electrons modelled with Global Maxwell-Boltzmann Model
  - Ions are modelled using the PIC model
  - Non linear Poisson solver
  - all occuring secondary effects are considered
  - secondary particle dynamics and external magnetic field are not considered
  - Velocity of the satellite is adressed in order to simulate ram / wake effects
  - maximum time step of 100 ms is chosen
    - due to the automatic time step algorithm the average time step was on the order of 30 – 60 ms
  - satellite capacitance is set to 1 nF

Simulation Results

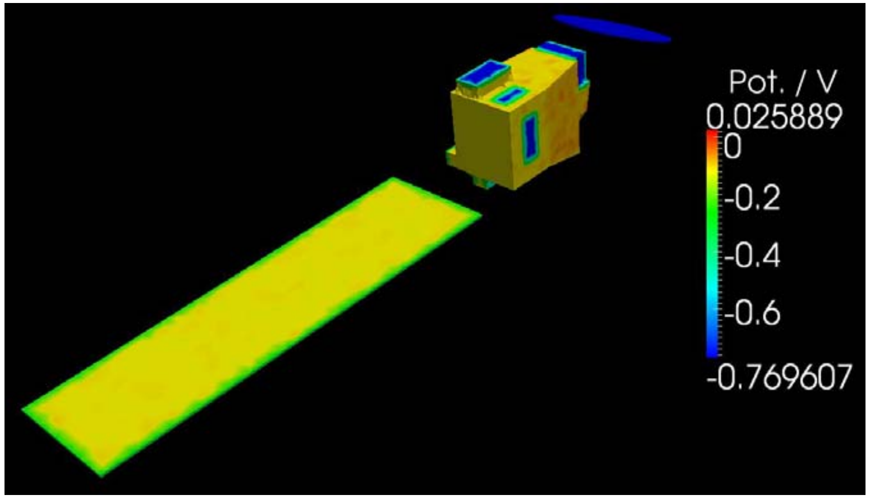
- Quiet LEO Environment

  Satellite Potentials

sunlit



eclipse

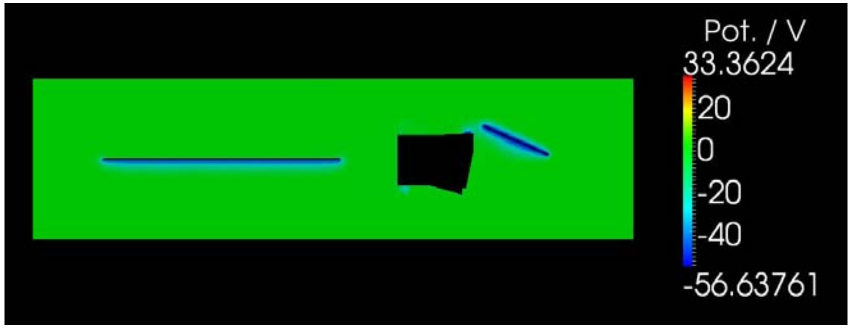


Simulation Results

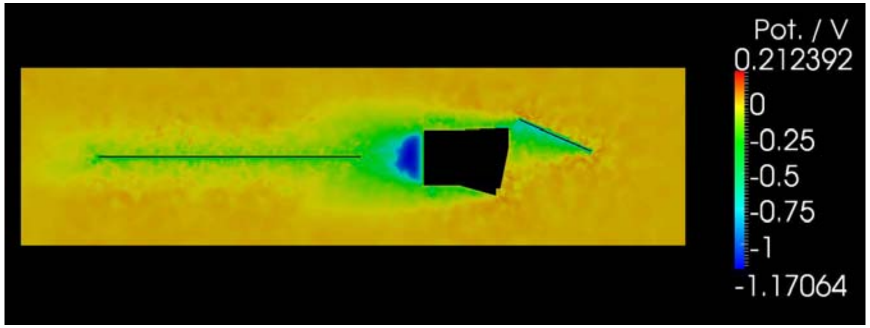
- Quiet LEO Environment

Plsama Potential

sunlit



eclipse



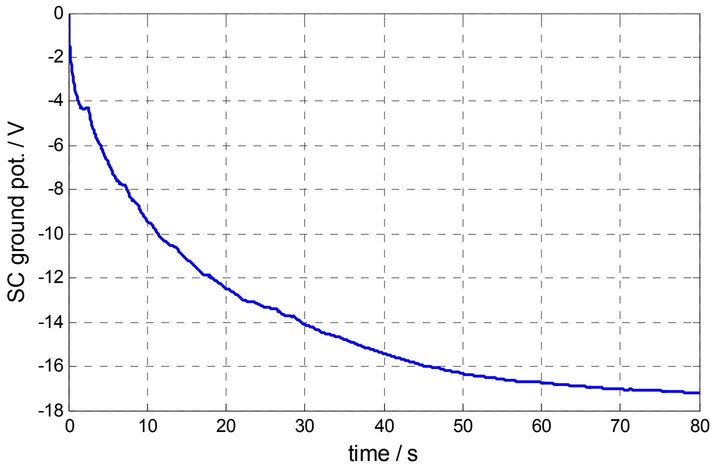
- All potentials are within the expected range; consistent to theory

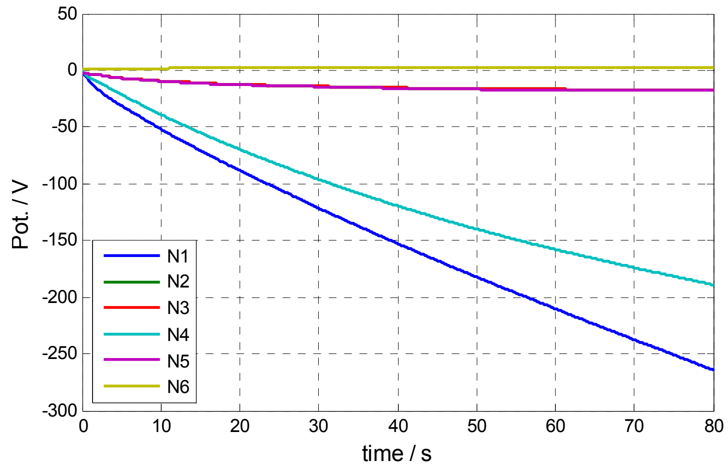
Simulation Results

- Fontheim Environment Sunlit
  - Structure potential and averaged surface potentials
    - Satellite ground potential of about -17 V

      → no risk for dangerous IPG
    - Maximum averaged dielectric surface potentials of -270 V

      → no risk for ESDs due to normal gradients (threshold 1000 V)



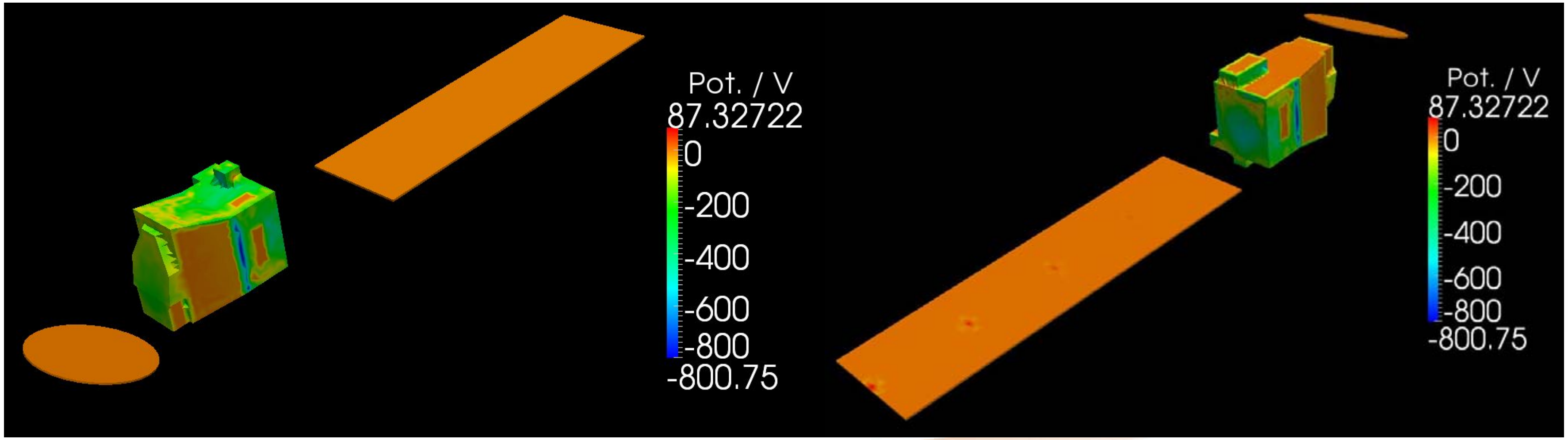


Simulation Results

- Fontheim Environment Sunlit
  - Surface Potentials

    → on MLI side parts locally increased potentials around -800 V

    → potential is still well below the threshold of -1000 V

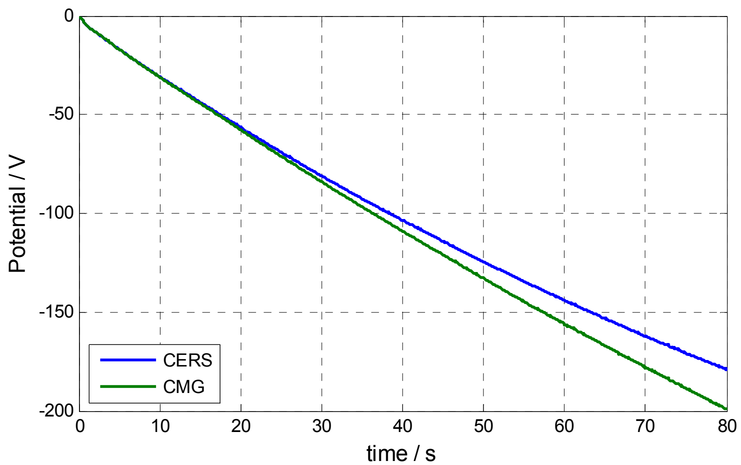


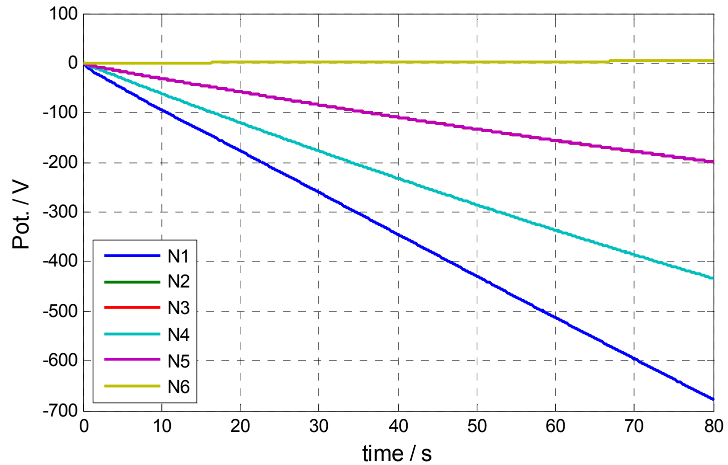
Simulation Results

- Fontheim Environment Eclipse
  - Structure potential and averaged surface potentials
    - Satellite ground potential drops to -200 V (CMG) / -180 V (CERS)

      → IPG exceeds the threshold; SA cover glass potential ≈ 0 V
    - Maximum averaged dielectric surface potentials of -680 V

      → no risk for ESDs due to normal gradients





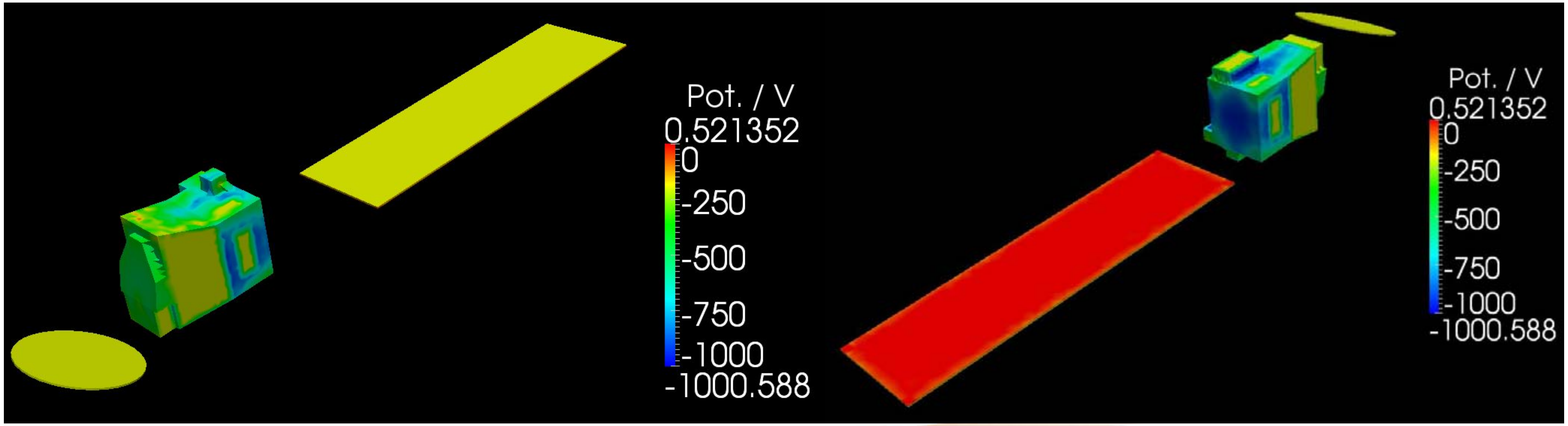
Simulation Results

- Fontheim Environment Eclipse
  - Surface Potentials

    → SA cover glass slightly positive -> IPG to structure -> arcing possible

    → on MLI side parts and at the rear increased potentials of up to -1000 V

    → potential differences still below the threshold (-1000 – -200 = -800 V)

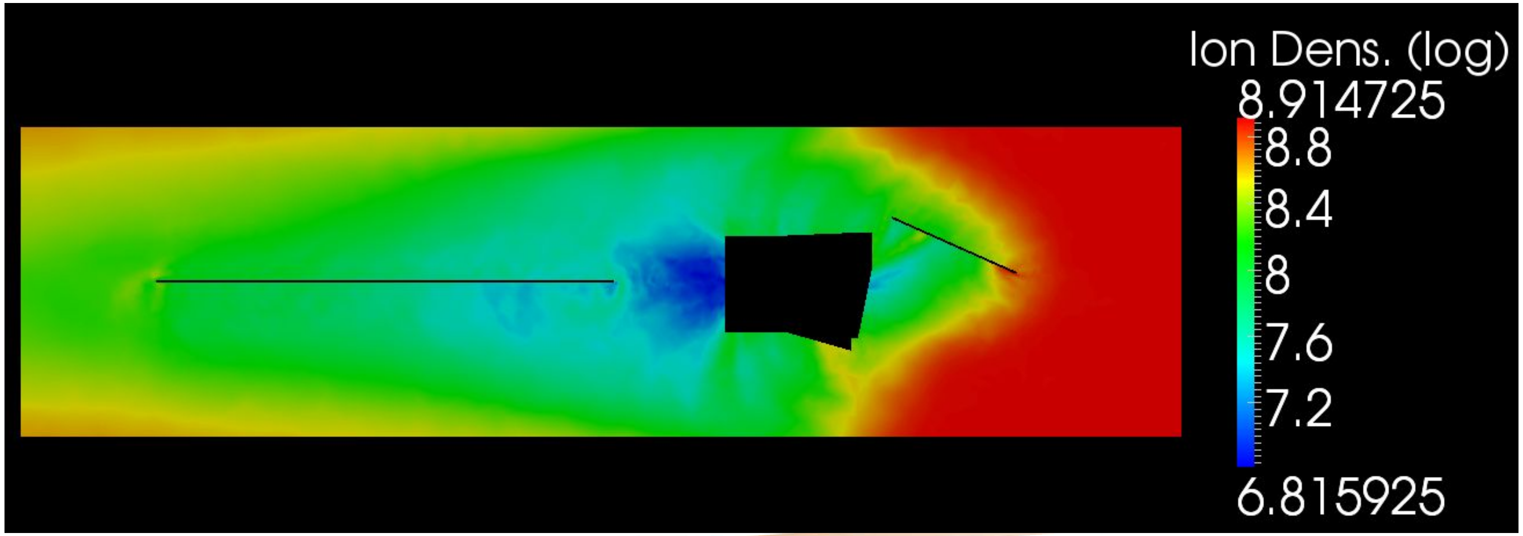


Simulation Results

- Fontheim Environment Eclipse
  - Ion Wake

    → Plot of the ion density illustrates nicely the wake effect

    → ion density behind the satellite body reduced by 2 orders of magnitude



Simulation Results

- Main Drivers of the Potentials and differences to the Sentinel 2 results
  - For Sentinel 2 the structure potential dropped to -240 V vs. -180 V for EC with the same cover glass conductivity

➢ CPR Reflector dish with conductive Ge foil on the ram face of the satellite

➢ ITO coated radiators (conductive and high SEE yield)

→ both effects help to limit the negative charging of the structure

➢ Ram / Wake effect and striving ion collection

→ influencing the local charging of dielectric surfaces on the satellite

➢ SA structure painted with conductive paint for EC

Simulation Results

- ESD Risk Assessment
  - Based on simulated potentials and the surface properties the characteristics of the ESD pulse can be calculated[(1)]
  - The IPG on the SA leads to the following inputs / results using $v_P = 3 \cdot 10^4$ m/s (velocity of the expanding plasma wave front)[(2,3)]

Input Parameters	Value
Coating Thickness	100 µm
Relative Permittivity	5,2
Surface Area	3,39 m^2
Simulated Voltage	200 V inverted
Surface Parameters	
Capacitance	1,14 µF
Stored Charge	228 µC

ESD characteristics	κ = 0,2	κ = 0,3	κ = 0,4
Half Width of pulse	36,82 µs	36,82 µs	36,82 µs
Released Charge	45,62 µC	68,43 µC	91,25 µC
Released Energy	8,21 mJ	11,63 mJ	14,60 mJ
Peak Current	1,24 A	1,86 A	2,48 A

κ represents the amount of charge blown off by the ESD event

Absolute worst case: Discharge of complete area with high κ

(1) Spacecraft Plasma Interaction Guidelines and Handbook, D. Rodgers et al, QinetiQ/KI/SPACE/HB042617

(2) ESDs on Solar Cells—Degradation, Modeling, and Importance of the Test Setup, J.-C. Matéo-Vélez et al, IEEE Transactions on Plasma Science **36**, 2395, 2008

(3) Electromagnetic Radiation Generated by Arcing in Low Density Plasma, B.V. Vayner et al, NASA Tech. Memorandum 107217

Simulation Results

- ESD Risk Assessment
  - Maximum released energy slightly exceeds the threshold given in ECSS for onboard units
  - However:
    - ESD is not occuring on the satellite body but on the SA; no scientific equipment
    - Low peak current of 2,48 A due to rather long duration of ≈ 37 µs
    - Energy will be dissipated in the SA / cells
  - Project has initiated a corresponding test by the SA supplier
  - Sentinel 1/2 SA has been tested for peak currents of up to 6 A

→ no problems are expected for EarthCARE SA

Conclusions

- Charging Simulation
  - Worst case auroral charging environment leads to IPG exceeding the ECSS threshold for eclipse conditions
    - ESD analysis performed for criticality assessment (energy, peak current)

    → Results can be considered as uncritical (peak current of about 2,5 A vs. 6 A tested for Sentinel 1/2 SA)
  - In all other scenarios the potentials on the satellite showed no violation of ECSS thresholds
- SPIS Tool
  - Possibility for the definition of new materials good improvement
  - Nice to have for future:
    Better parallelization of the simulation process