SPIS-GEO

Adapted Numerical Models

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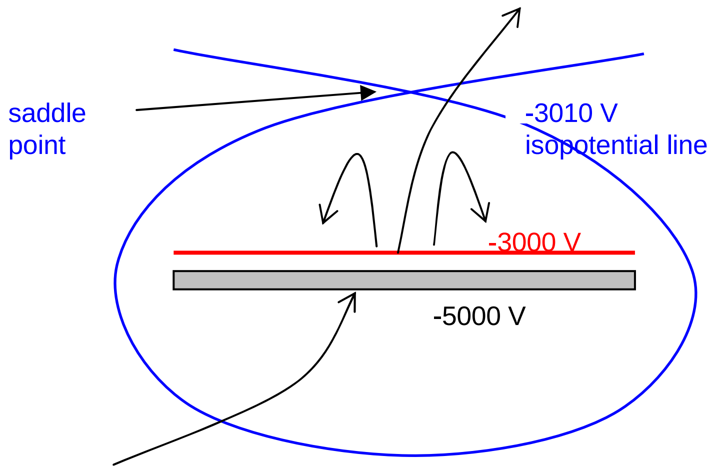
Spacecraft charging in GEO/MEO

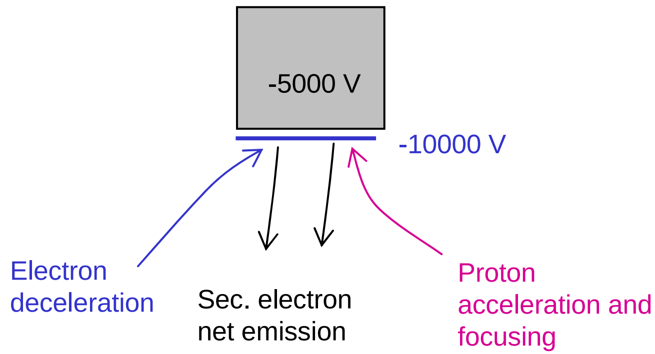
- Worst-case environment lead to severe absolute and differential charging

Parameter	Unit	Maxwellian plasma population			
		Electron 1	Ion 1 (H+)	Electron 2	Ion 2 (H+)
Density, n	cm^-3	0.2	0.6	1.2	1.3
Temperature, T	eV	400	200	27 500	28 000
Equilibrium potential	V	≈ - 38 000 (if no secondaries)			

At sunlit
- Dielectric charging is controlled mainly by photoemission and conductivity
- Inverted potential gradient situation : solar panel cover glasses

At shade
- Dielectric charge is controlled by eq. of electron and proton current + secondary electron emission under electron and proton impact + conductivity
- Often in normal gradient situation



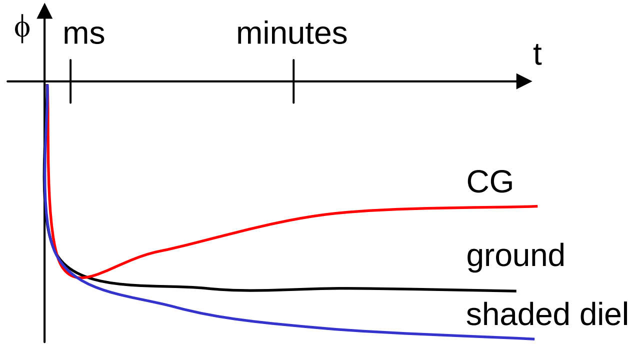


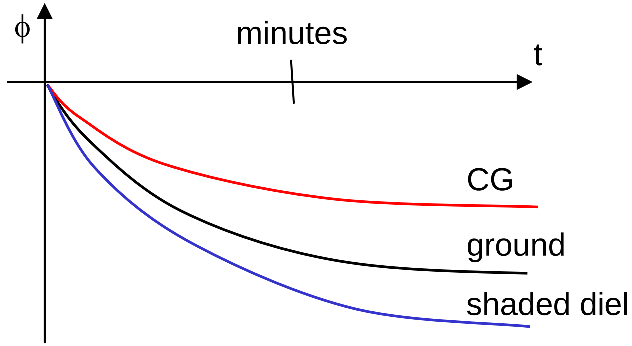
Spacecraft charging in GEO/MEO

- Time scales ($C.dV/dt = I_{net}$)
  - C_{sat} is low → spacecraft ground potential quickly adapts to balance currents (ms scale)
  - C_{diel} is large → takes minutes to charge

If total photoemission current < total electron current
- SC quickly gets negative
- photoemission slowly makes SA more positive
- progressive barrier of potential
- differential current at shade makes +- charging

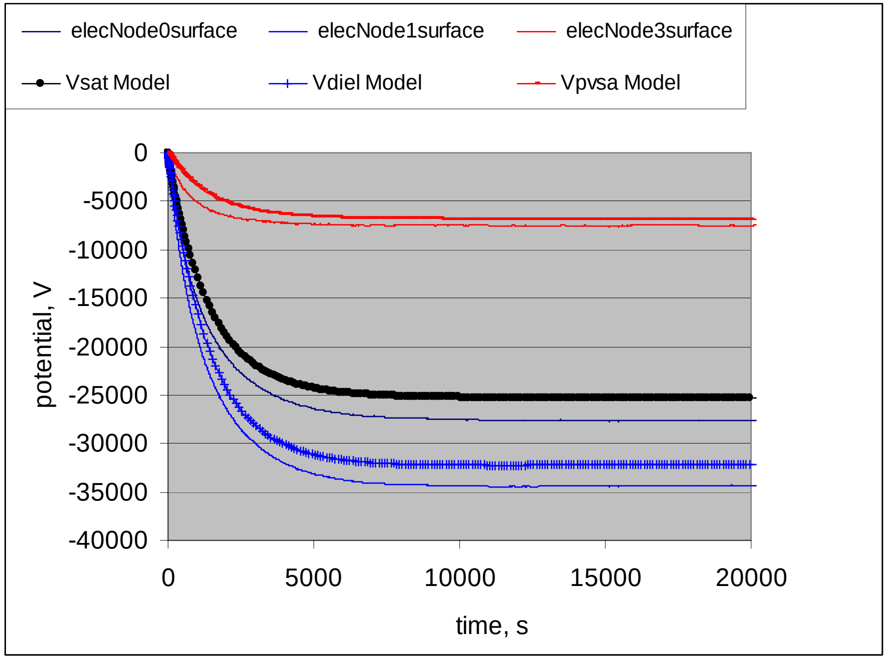
If total photoemission current > total electron current
- SC should stay close to zero
- solar panel front side tend to stay close to zero
- negative current on rear side → diel charging of SA
- slow charging of rear side to negative potential
- progressive barrier of potential

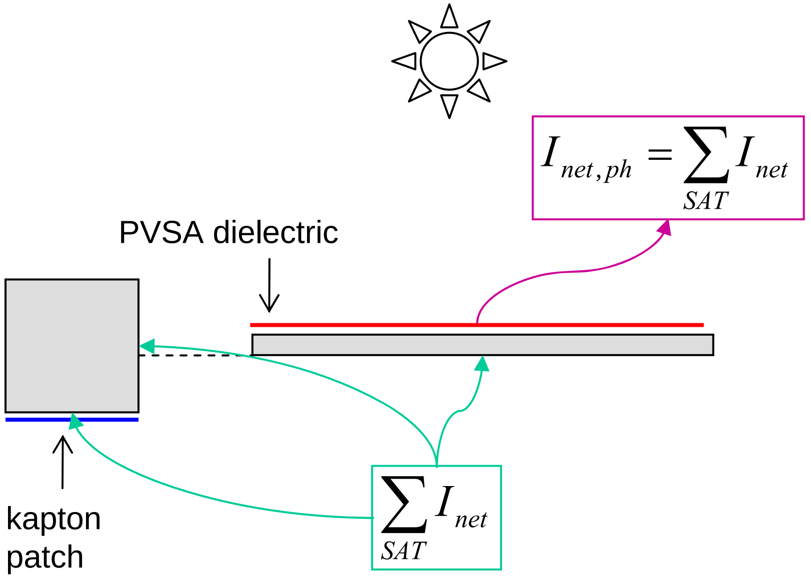




0D modelling

- Applicable when total photoemission current > total electron current
- Here: ECSS worst-case / SEE under electron impact / photoemission / no conductivity / no SEE under proton impact / height of barrier for SA photoelec
- Good comparison between analytical and SPIS simulation



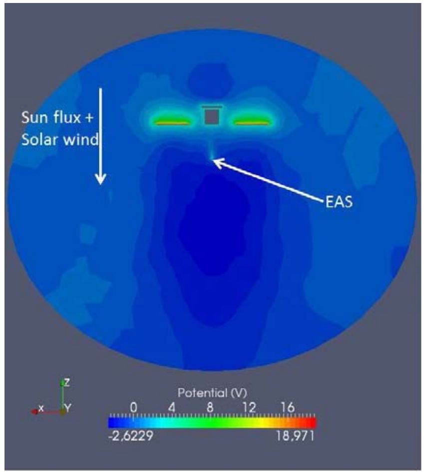


- Cheap 0D model to estimate charging level and dynamics at first order (some limitations however = 3D barriers)

SPIS GEO, FP, Noordwijk, NL, 20/03/2013

ONERA

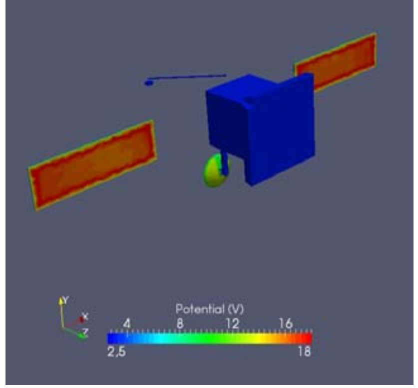
SPIS simulation principle

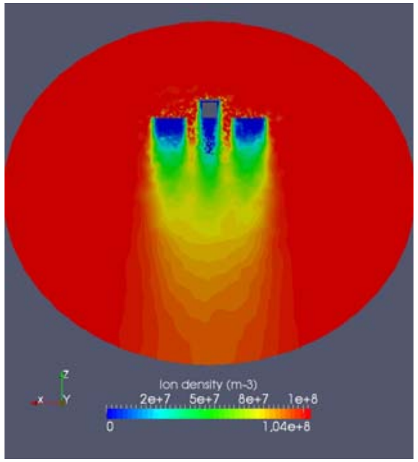


① Electric field from:
-Particle densities
-Boundary conditions

④ Potential on S/C:
-Current balance
-RLC circuit between S/C elements

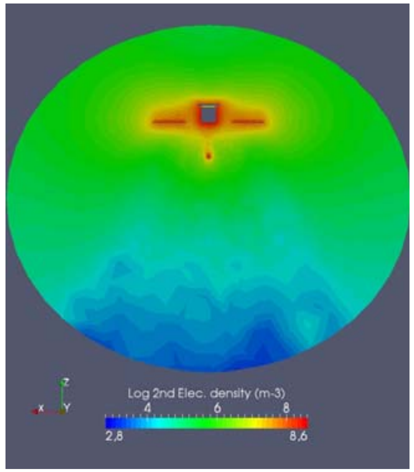
courtesy Stanislas Guillemant (IRAP, ONERA)





② Particle Transport:
-Space environment
-Secondaries or Sources from S/C

③ Interaction with S/C:
-SEE by electrons
-SEE by protons
-Photo-emission
-Sources

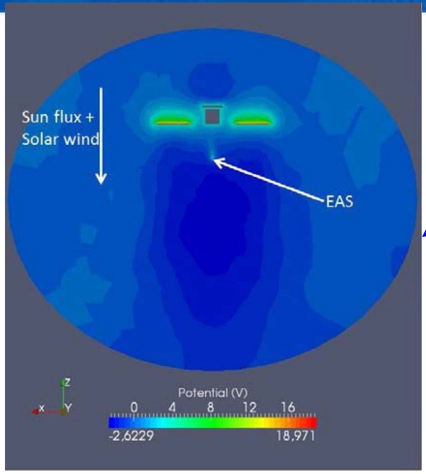


SPIS-GEO needs adapted numerical kernel

- Objective 1: be realistic of GEO charging
  - Extends the SPIS-TD capabilities
  - Upgrade of particle interaction with spacecraft
  - Eclipse exit with evolution of material conductivity
  - Self-shading
  - ECSS and NASA environment worst-cases

- Objective 2: Ease of use
  - More than 200 numerical parameters !
  - Tuned code with pre-defined parameters adapted to GEO/MEO
    - Loading XML files
    - Available for ECSS, NASA worst case
    - Eclipse exit
  - Live spacecraft potential and currents monitoring
  - Increased performance and robustness

Numerical adaptations



Electric field Boundary Conditions

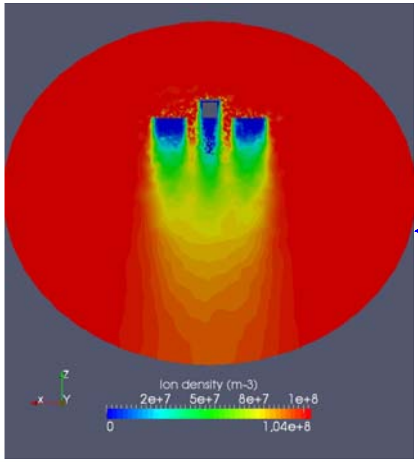
λ_D > 100 meters ⇒ vacuum-like BC : $\phi \sim 1/r$

Has the same effect as using bigger box ⇒ save large CPU time

Plasma dynamics

Populations, plasma and spacecraft integration loops : automatic calculations of duration and time steps (plasma frequency, transport across the simulation box)

⇒ simplify numerical settings



Ambient particles

Full PIC or Hybrid : Hybrid (fluid electrons)

Because negative spacecraft and no barrier justifies Maxwell-Boltzmann equilibrium distribution for electrons ⇒ save large CPU time

Associated with non-linear Poisson equation

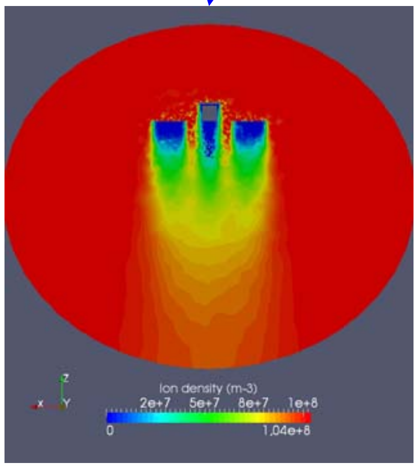
Numerical adaptations

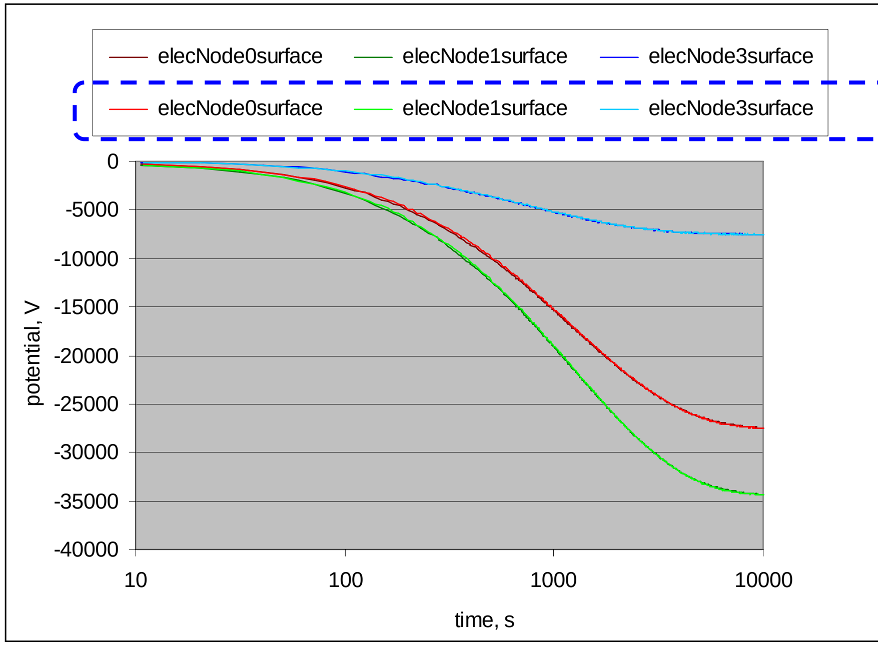
Ambient particles

Backtracking method for ions ⇒ increase accuracy of collected current

Backtracking + PIC ions or backtracking (only) ions : backtracking only

Because space charge is negligible ⇒ save CPU time (factor ~4)





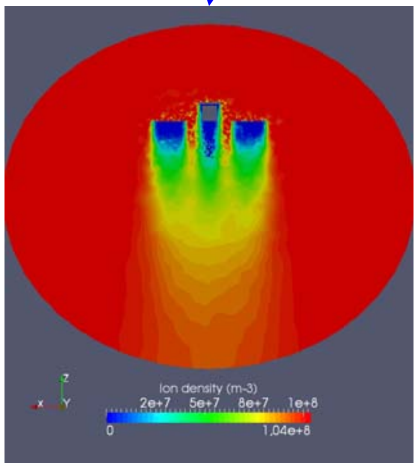
Numerical adaptations

Ambient particles

Two GEO worst-cases from ECSS and from NASA guideline

ECCS-E-10-04A Worst-case bi-Maxwellian plasma environment for outer magnetosphere

	Electron density (m-3)	Electron temperature (eV)	Ion density (m-3)	Ion temperature (eV)
Pop 1	2,00E+05	400	6,00E+05	200
Pop 2	1,20E+06	27500	1,30E+06	28000



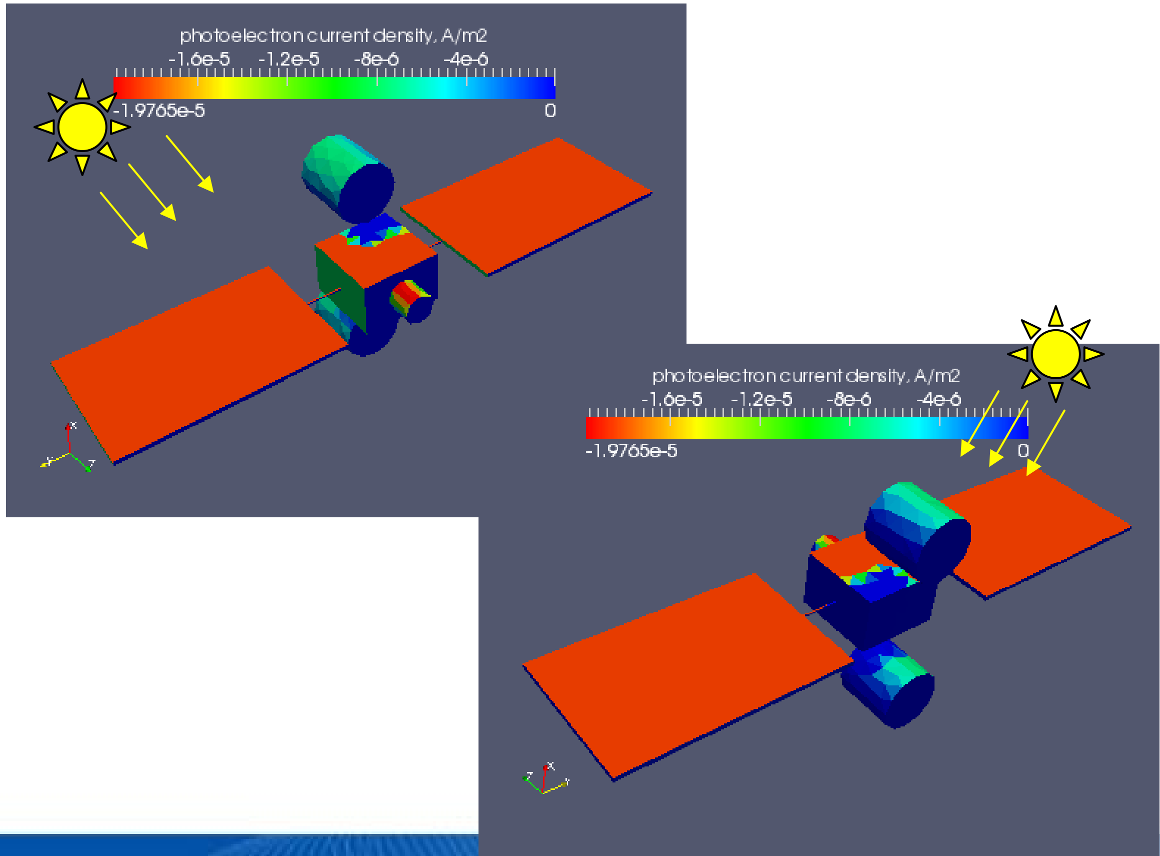
NASA guideline (Purvis 1984)

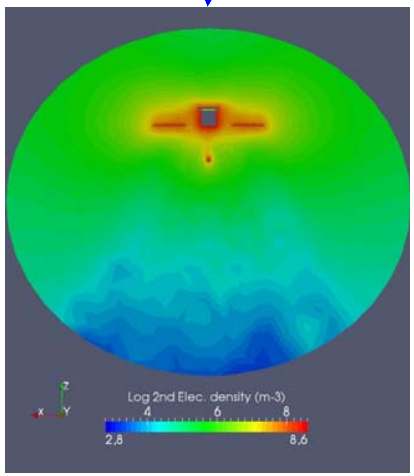
	Electron density (m-3)	Electron temperature (eV)	Ion density (m-3)	Ion temperature (eV)
Pop 1	1.12E+06	12000	2,36E+05	29500

Numerical adaptations

Interactions with SC

Self-shading using ray-tracing technique ⇒ simplify geometry definition





Numerical adaptations

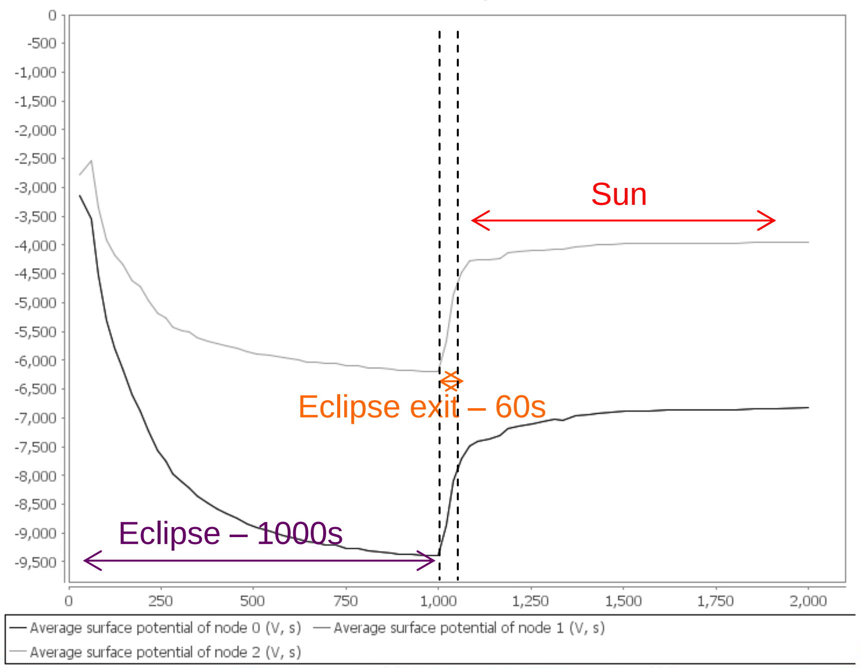
Interactions with SC

Eclipse exit

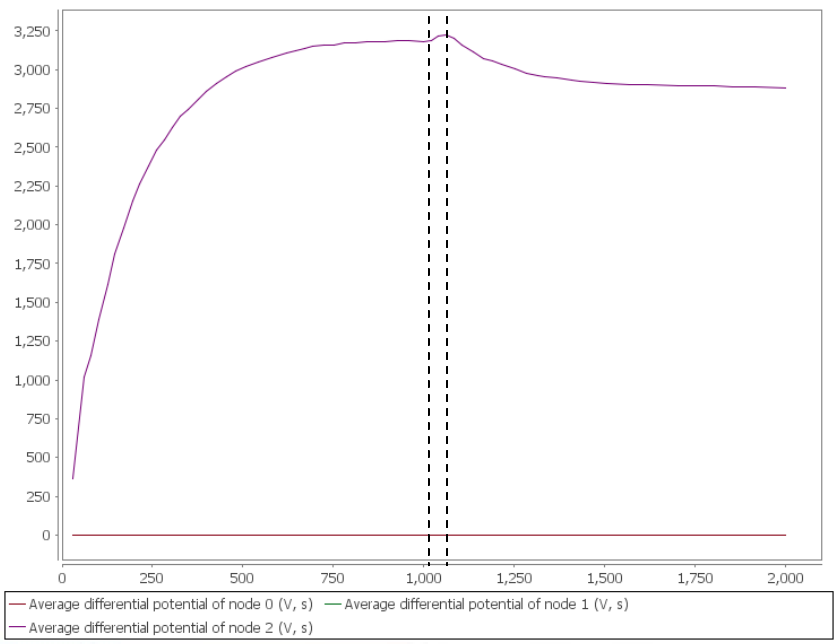
- Progressive sun flux (using ASCII file)
- Change of dielectric conductivities to mimic temperature evolution using extended material property BUC = BUC(time)

⇒ more realistic of hazardous configurations

Absolute potentials



Differential voltage



Numerical adaptations

Interactions with SC

Secondary electron emission under electron, photon and proton impact automatically set (time step internally calculated, default densification, temperature) $\Rightarrow$ Simplify numerical settings

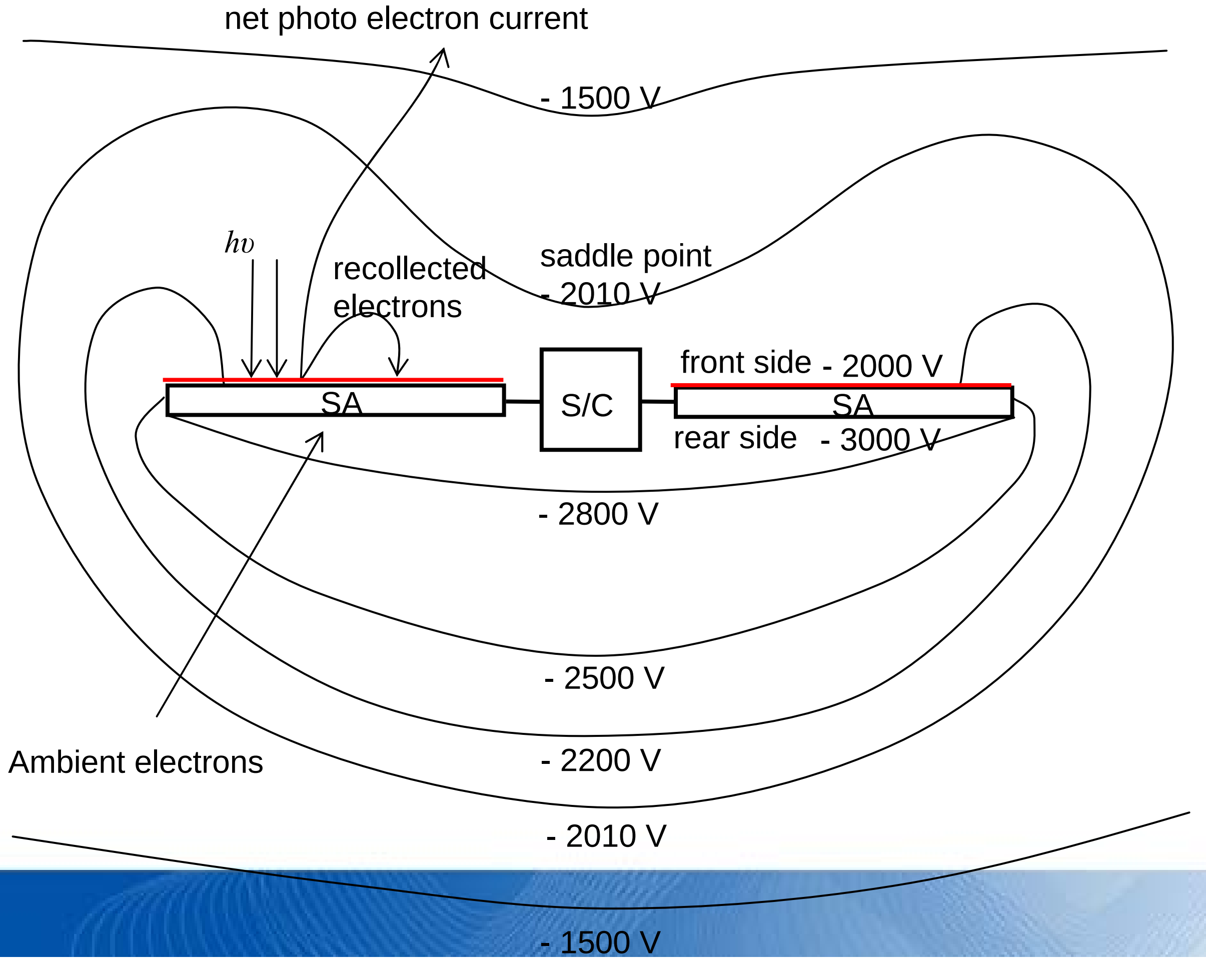
Secondary electron emission under proton impact

- Ions focused by negative spacecraft (OML) : $J_{H+} = J_{H+,\infty}\left(1 - \frac{q\phi_{SC}}{kT_{H+}}\right)$
- Focalization of low energy ions lead to large currents
- Associated with Secondary emission under proton impact up to 3 or 4 at 10 keV
- Multiplication factor up to 40 or 400 on positive current wrt to undisturbed situation → impacts SC potential
- Effect illustrated during the validation campaign made by OHB-Sweden

Numerical adaptations

Potential on SC

Barrier current scaler developed during SPIS TD set as default to take account of recollection of secondaries by barriers of potential on sunlit face $\Rightarrow$ save CPU time (permit the use of larger time steps simplify numerical settings)



Numerical adaptations

Potential on SC

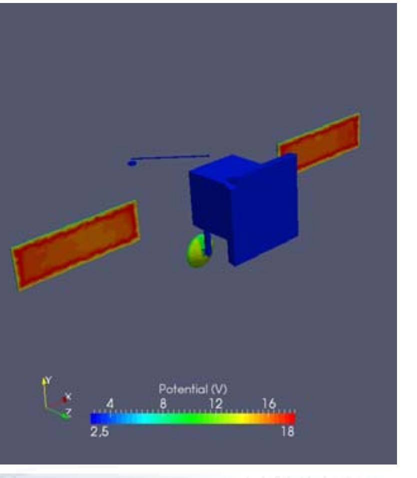
By default: bulk, surface and radiation induced conductivity

Circuit solver using iterative Conjugate Gradient Square method instead of Gauss inversion method for linear systems

$\Rightarrow$ save CPU time

$\Rightarrow$ permit the use of refined dielectric areas

Csat of 10 nF by default



Levels of control

- 4 levels of expertise for the 200 global parameters: from the combo box
- Low expertise (20 parameters)
  - Plasma properties
  - Sun flux
  - Duration of simulation and maximal time step (duration/20 is a good basis)
  - Spacecraft capacitance
  - Eclipse exit activation

- Medium expertise (40 parameters)
  - Deactivate automatic time steps control (spisGEO mode)
  - Control time steps
  - Activate/deactivate/modify plasma and secondary electron models
  - Activate/deactivate conductivities

- Advanced and Expert (140 parameters)

Live monitoring (vs. time)

- Spacecraft potentials
  - Absolute
  - Differential
  - dV/dt
- Currents
  - Total by nodes
  - Detailed by nodes
- Number of super particles
- Total energy of populations

- Quick check of results and simulation convergence