RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

ARTENUM, PARIS
Science & Groupware

La Région Occitanie
Pyrénées - Méditerranée

ONERA

THE FRENCH AEROSPACE LAB

www.onera.fr

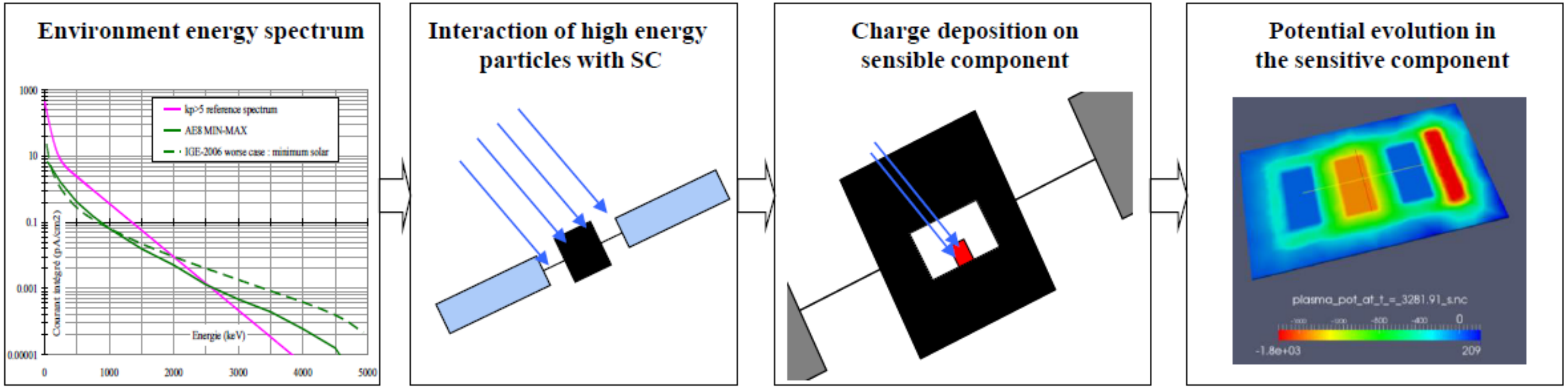
Time-dependent electron environment effect on the internal charging dynamics by SPIS-IC simulations.

DPHY/CSE

H. Balboa, P. Sarrailh, B. Jeanty-Ruard, JC. Mateo-Velez, T. Paulmier

Contents

Introduction



1) High energy particles in the environment: electrons or protons

2) Penetrate and stop inside the SC:

- Electron with energy from 100s keV to 100 MeV stopped inside the SC

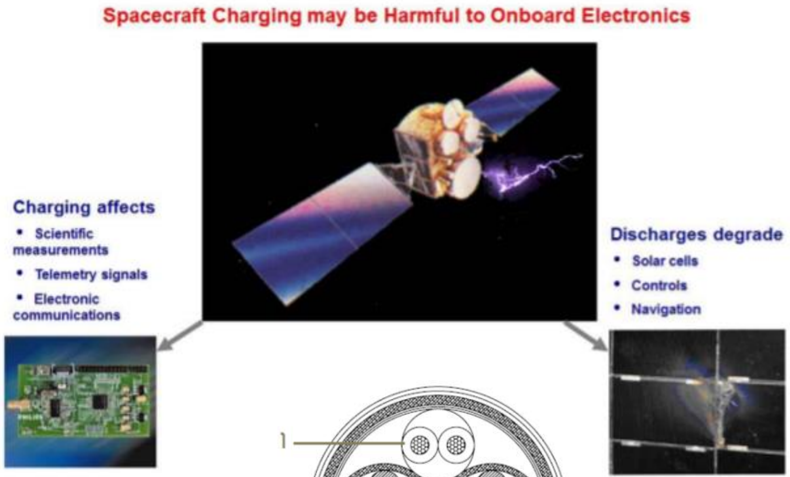
3) Deposition of the charge and creation of a RIC => **electric field buildup**

=> Risk of internal electrostatic discharge (IESD) inside the SC payload and/or sub-systems

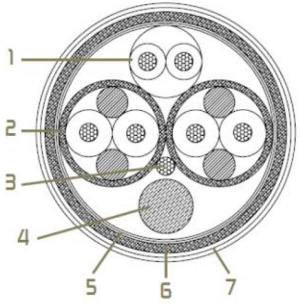
Why is internal charging a problem?

- Until the nineties, more than 20 satellites have shown damages by IESD (2)

- Typical sensible components can be for instance; motherboards, cables, connectors, optical lens, etc.



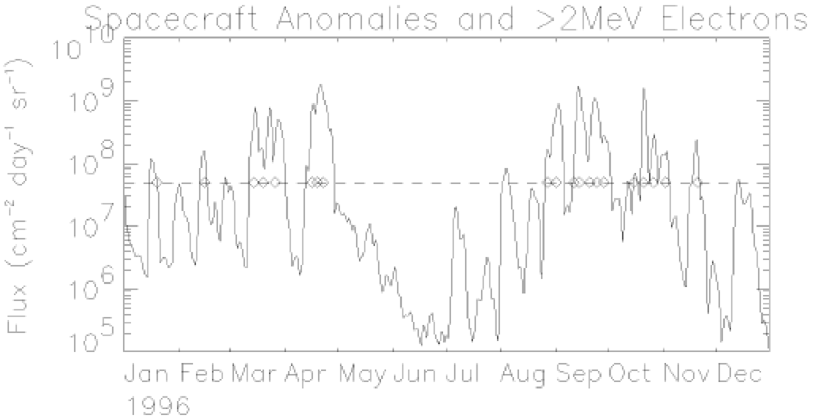
Complicated geometries found in the sensible components may enhance the electrical potential buildup => danger of IESD



SpaceWire IEEE 1394 where 1,4,5 and 7 are dielectrics, else conductors

Why to take into account a variable environment?

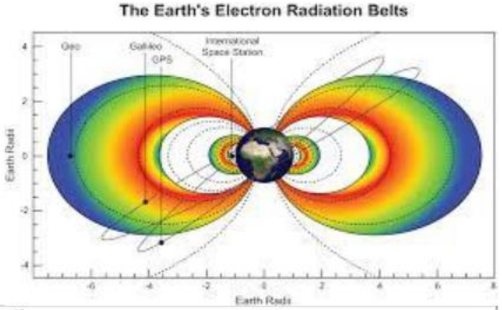
- The spacecraft will be summited to variable Irradiation field
- High energy electron periods may last for days to weeks
- Anomalies may occur every time the irradiation field reaches a certain threshold
- Once an internal charging anomaly occurs, it may recur in less extreme environments [3]

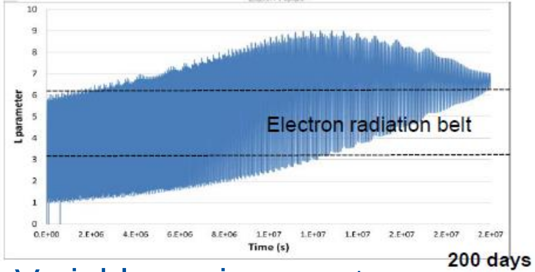


Times of occurrence of a certain anomaly on Dra-δ (◊) compared to > 2 MeV Electron flux from GOES [3]

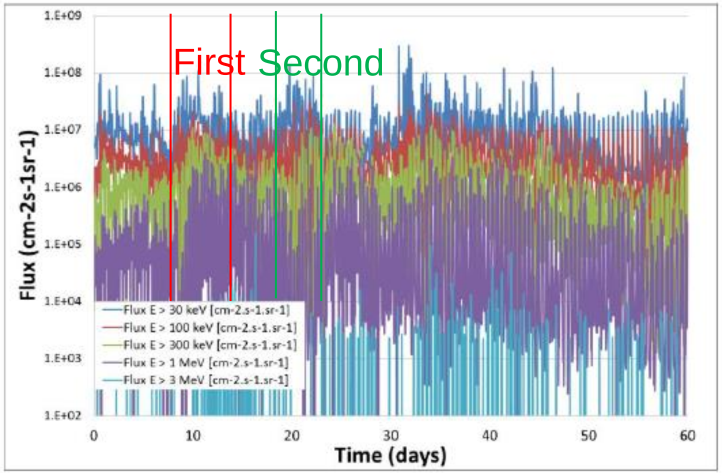
- The charging behavior takes tens of hours to reach a steady state
- The radiation induce conductivity evolves with time - characteristic time of 1 hour
- These evolutions are non monotonous and specific to a material

Electron Environment during Electric Orbit Raising (EOR)





T0 = August 2015 → 3 successive events (medium)



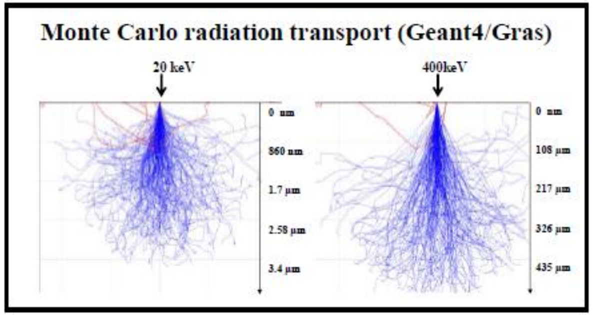
(LEO and MEO measurements extrapolated to equatorial plan)

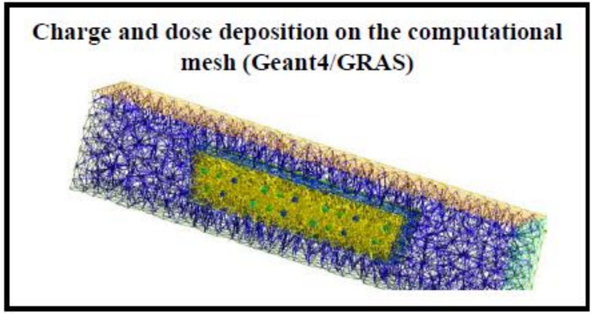
Variable environment

- At the scale of internal charging time, the dynamic of an magnetospheric event is important => radiation belts are not populated all the time (relaxation time of about 1 week after an event)
- An EOR spacecraft, low altitude perigee and high altitude apogee, period of several hours => cross several times a day the radiation belts

=> Environment change has the same time scales as RIC or charging times

Simulation Chain 1 Gras/Moora





Geant 4 is a toolkit for the Monte Carlo simulation of the passage of particles through matter

GRAS is a Geant4-based tool enabling common radiation analyses, such as; charge deposit and dose.
Moora is a user-friendly interface

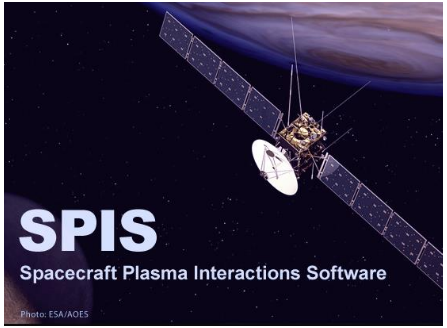
Input:

- Geometry GDML 3D (shielding + component)
- Energy spectrum
- Materials
- Geometry GMESH 3D (component in finite elements)

Output:

Irradiated Geometry: 3D Dose and charge

Simulation Chain 2 SPIS-IC



Input:
- Irradiated geometry GMESH
- Environment

↓

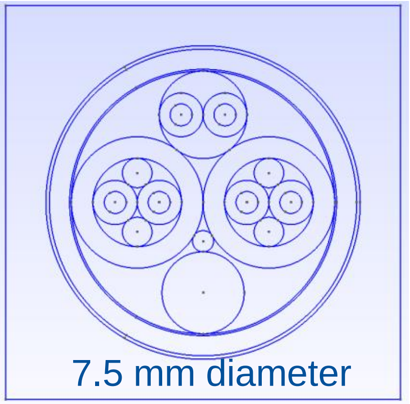
Output: 3D electric potential evolution

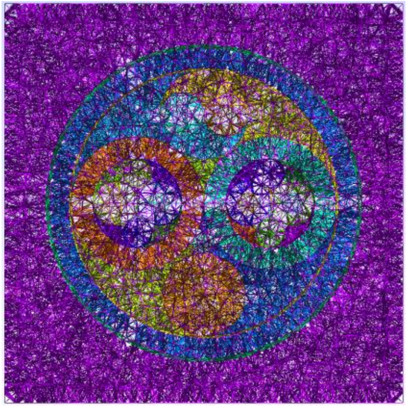
Internal charge transport equations solved on the computational mesh by a finite element method:

1. Poisson equation
2. Continuity equation for the net charge
3. Ohm's law

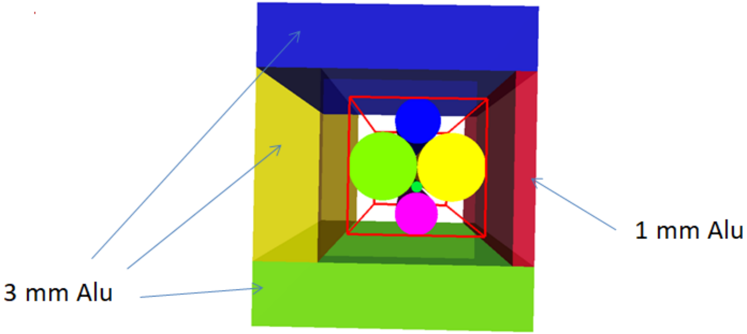
Conductivity model:
- Field induced conductivity
- Bulk conductivity
- Radiation induced conductivity

Application case SpaceWire

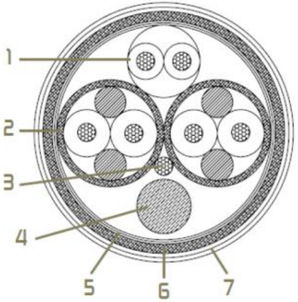




Non uniform shielding



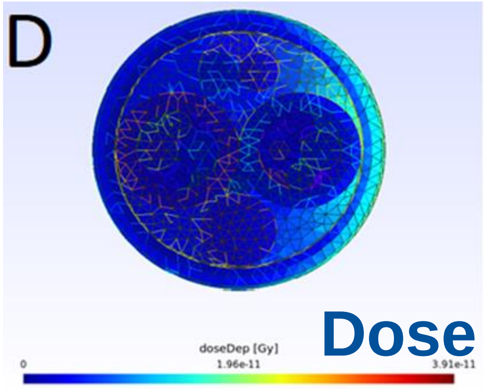
GDML geometry



GMSH geometry

1.- one 26 AWG unscreened pair, 2- two CPR 26 AWG screened pairs, 3- one 2619 AWG drain wire, 4.- PTFE filler, 5.- two polymide layers, 6.- brained shield and 7.- outer jacket.

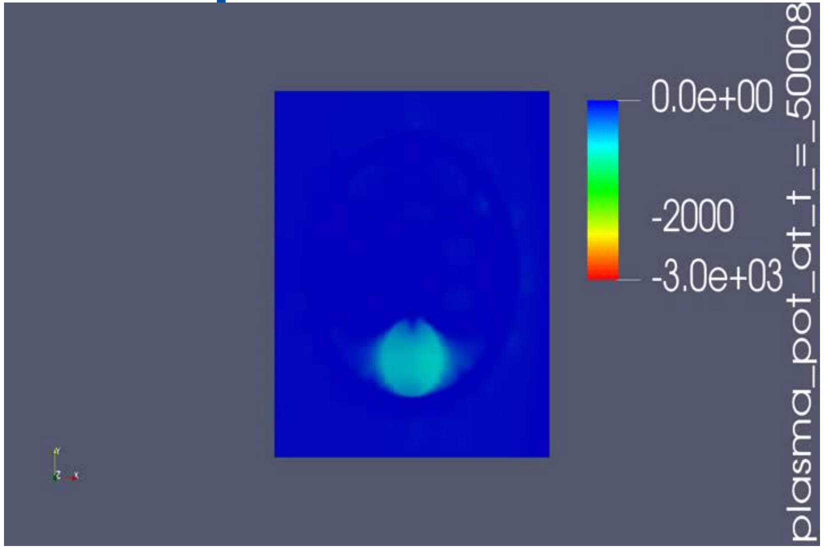
Source type = cosine emission law



Dose (Gy)

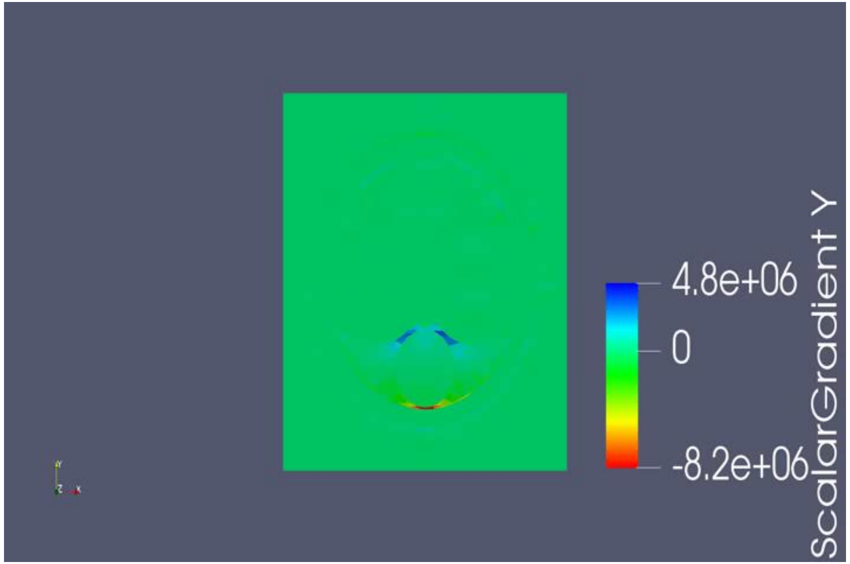
2.4 MeV > E > 1.6 MeV

Electric potential and field evolution 1



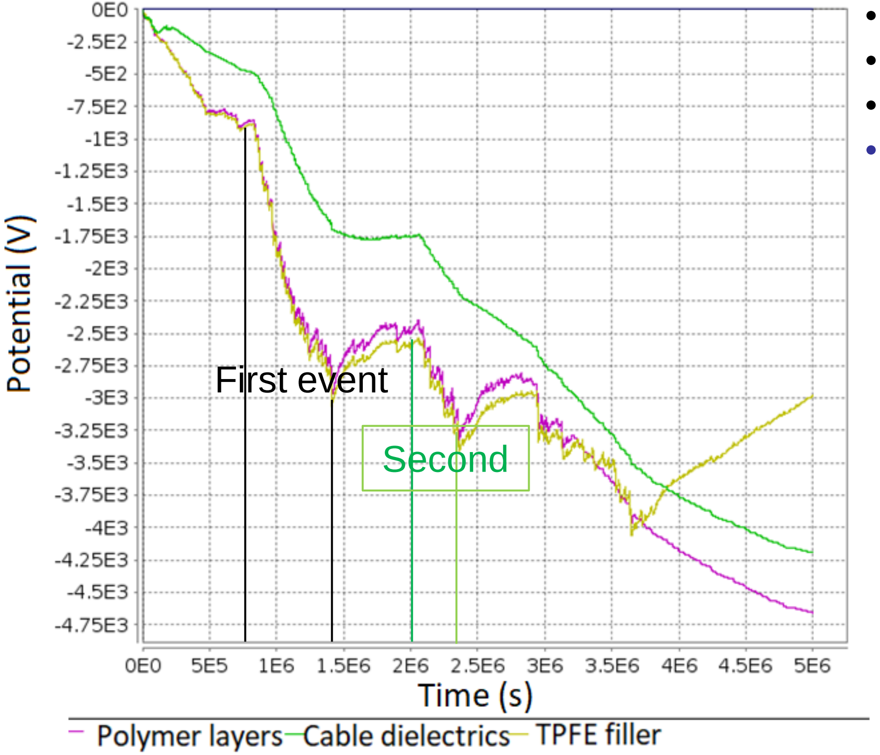
Electric Potential

Electric Field

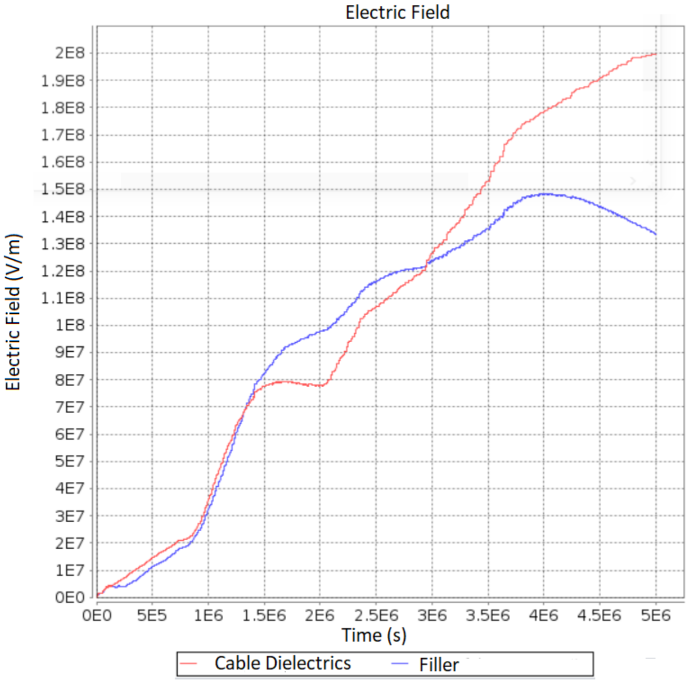


Total simulation time 60 days
Frames = every 10 days
Electric potential concentrated on the PTFE filler
Maximum potential 4 500 V

Continuation



- Highest potential found in the polymer layers and filler
- High potential found in the dielectrics inside the unscreened 26 AWG cable
- Not far of the dielectric strength limit [4]
- Events related with a decrease in the potential
- The events accumulate the potential
- Discharge is possible



Conclusion

SPIS-IC internal charging charge transport

- Open source https://www.space-suite.com/
- 3D time dependent fast accurate IC solver
- Validated on experimental data
- Assess the possible discharge risks in payload

Simulation results shows

- Time dependent effect of the RIC
- Time fluctuation of the environment and the EOR orbits
- Geometry dependency of charge conduction

Thank you for your attention

Acknowledgments

The authors thank Région Occitanie (Programme Recherche et Société(s) 2018) and the European Union (Fonds Européen de Développement Régional)

for their support and confidence into the SpaceSuite initiative through the SpaceSuite-Ô project

l'Europe s'engage en Occitanie

UNION EUROPÉENNE

La Région Occitanie Pyrénées - Méditerranée

References

2 G. L. Wrenn and R. J. K. Smith The ESD threat to GEO satellites: Empirical models for observed effects due to both surface and internal charging,, in Proc. Environ. ModellingSpace-Based Appl., Symp. (ESA SP), 1996, p. 121.

1 Shu T. Lai and Kerri Cahoy. Spacecraft Charging, Boston Collage free documents. http: https://www.bc.edu/content/dam/files/research_sites/isr/pdf/2017%20Lai%20%26%20Cahoy%20-%20Encyclo.pdf

3 D J Rodgers and K A Ryden, Internal charging in space, JOUR 2001/10/31 Volume 476 p. 25

4 Polymeterdatabase https://polymerdatabase.com/polymer%20physics/Dielectric%20Strength.html

Moreover, several studies demonstrated that RIC is usually dependent on temperature for polymers [Paulmier 1-2, Dennison] and for ceramics [Kaffky, Hunn]. Figure 56 illustrates as well this dependency for Kapton and Teflon. Fit of experimental feature with empirical laws is not straightforward since several temperature activated physical processes can steer RIC. As we will see later, the most frequently used formula to express evolution of RIC as a function of temperature is the following [Gillepsie]:

$$RIC = k_{RIC}.(dD/dt)^{\Delta}$$

ONERA
THE FRENCH AEROSPACE LAB

GEN-F157-1.

FR 1/23284 DESP

DECEMBER 2015

UNCLASSIFIED

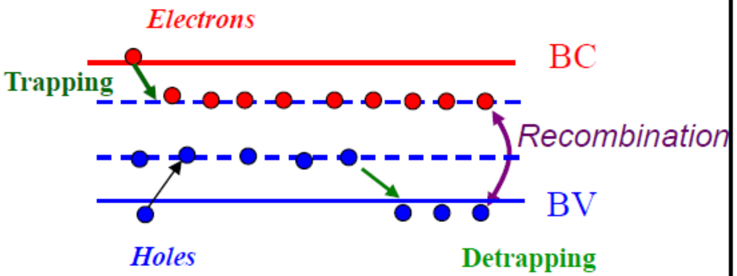
-39-

$$\text{with } \Delta(T) = \frac{T_1}{T+T_1} \text{ and } k_{RIC}(T) = e\mu_0 \left[\left(\frac{\rho_m}{s\Sigma n_0 T_1} \right) \left(\frac{m_e^*}{3k_B T} \right)^{1/2} \right]^{\Delta(T)} \left[2 \left(\frac{\sqrt{m_e^* m_h^*} k_B T}{2\pi\hbar^2} \right)^{3/2} \right]^{1-\Delta(T)}$$

for which T_1 is reference temperature describing the energy distribution of traps, s is the electron-hole recombination cross-section, Σ the averaged energy required for the generation of electron-hole pairs, m_e^* and m_h^* the effective mass for electrons and holes, ρ_m the material density, and μ_0 the charge mobility.

Model based on band theory of solid :

- Single level of localized traps for electrons and holes → deep levels
- Electron / hole pairs Generation by the electron beam (ionization)
- Trapping of free charges
- Free charge recombines with a localized charge



System of 4 evolution equations

$$\frac{dn}{dt} = g - \alpha n p_t - \frac{n}{\tau_n} + \frac{n_t}{\tau_{nt}}$$

$$\frac{dn_t}{dt} = \frac{n}{\tau_n} - \frac{n_t}{\tau_{nt}} - \alpha p n_t$$

$$\frac{dp}{dt} = g - \alpha n_t p - \frac{p}{\tau_p} + \frac{p_t}{\tau_{pt}}$$

$$\frac{dp_t}{dt} = \frac{p}{\tau_p} - \frac{p_t}{\tau_{pt}} - \alpha n p_t$$

Free charge transport (convection and diffusion) **not take into account** at the local scale

With generation rate:

$$g = \frac{\Delta E}{W}.\exp\left(-e^2/\varepsilon.k.T.r_0\right)\left(1 + e^3.E/8.\pi.\varepsilon.k^2.T^2\right)$$

Conductivity from local transport equation :

$$J = J_n + J_p = (n.\mu_n + p.\mu_p).E$$

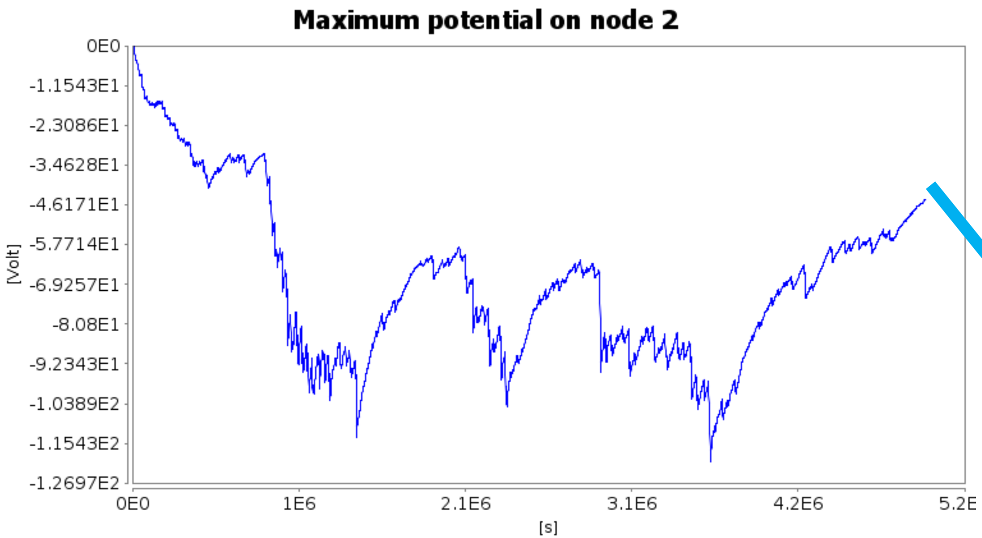
$$J = \sigma.E$$

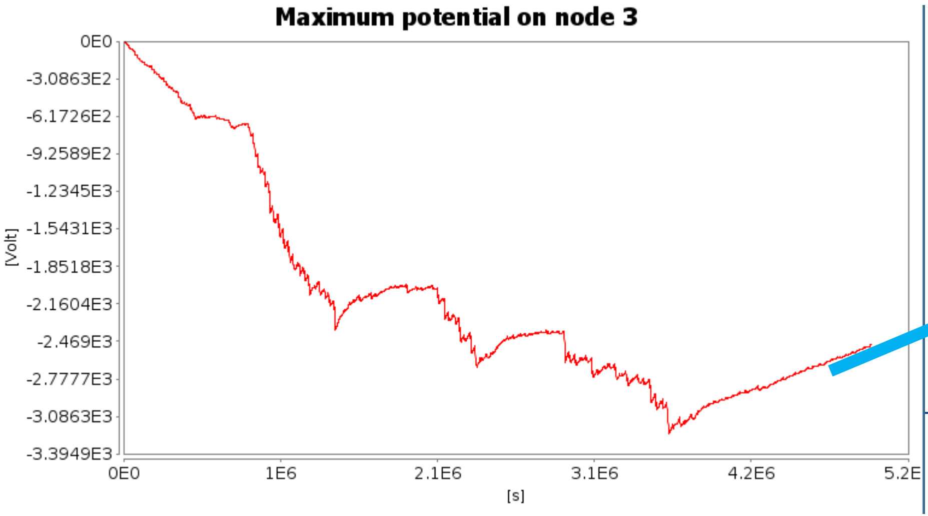
⇩

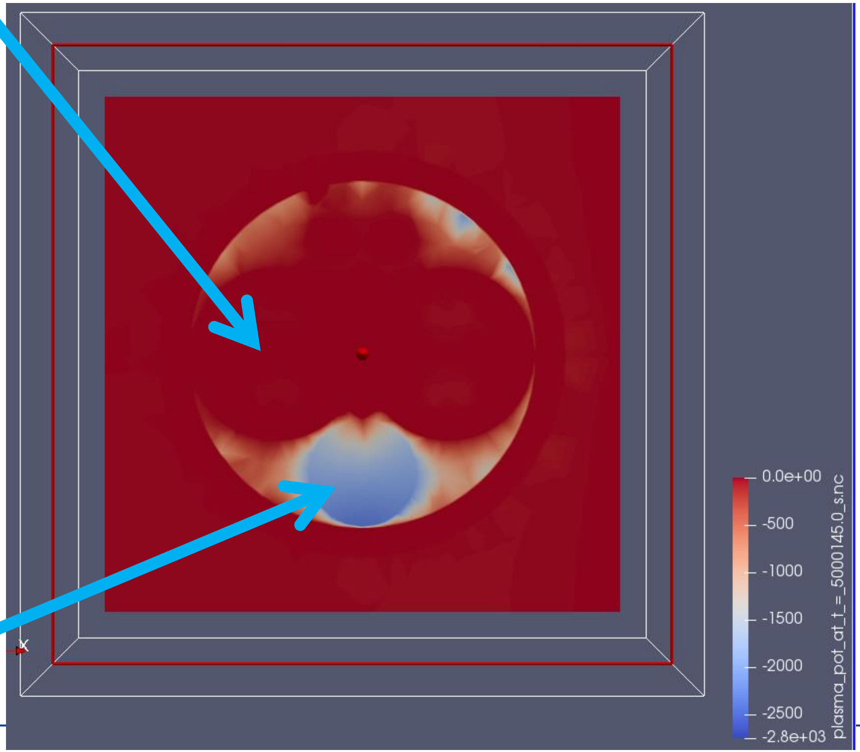
Conductivity used in IC solver

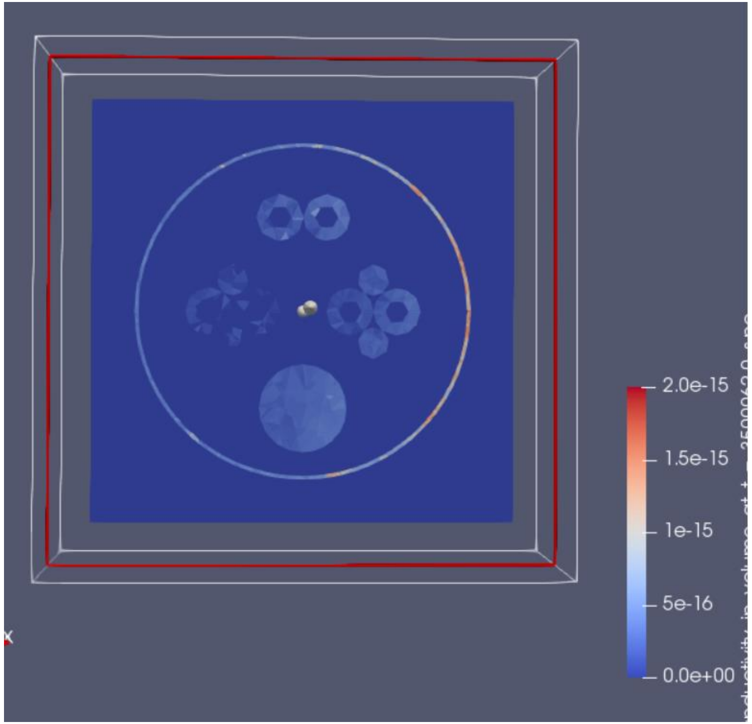
$$\sigma = n.\mu_n + p.\mu_p$$

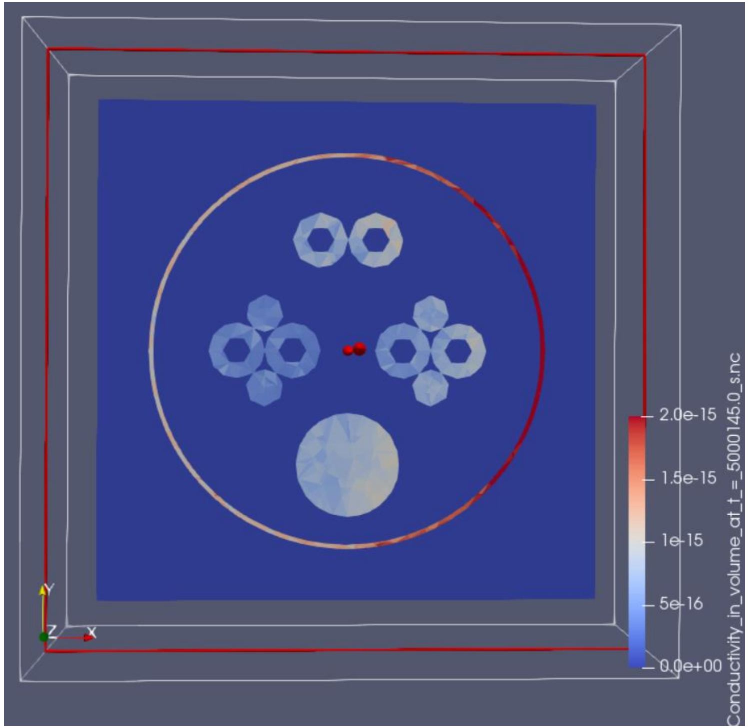
→See Rémi Pacaud poster P-A-34


Maximum potential on node 2
0E0
-1.1543E1
-2.3086E1
-3.4628E1
-4.6171E1
-5.7714E1
-6.9257E1
-8.08E1
-9.2343E1
-1.0389E2
-1.1543E2
-1.2697E2
[Volt]
0E0
1E6
2.1E6
3.1E6
4.2E6
5.2E
[s]


Maximum potential on node 3
0E0
-3.0863E2
-6.1726E2
-9.2589E2
-1.2345E3
-1.5431E3
-1.8518E3
-2.1604E3
-2.469E3
-2.7777E3
-3.0863E3
-3.3949E3
[Volt]
0E0
1E6
2.1E6
3.1E6
4.2E6
5.2E
[s]


0.0e+00
-500
-1000
-1500
-2000
-2500
-2.8e+03
plasma_pot_at_t_=_5000145.0_s.nc


2.0e-15
1.5e-15
1e-15
5e-16
0.0e+00


2.0e-15
1.5e-15
1e-15
5e-16
0.0e+00
Conductivity_in_volume_at_t_=_5000145.0_s.nc
Y
Z
X