Internal charging review of needs and perspectives with SPIS

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retour sur innovation

Initial needs in internal charging

- New ESA missions
  - JUICE
- New needs of commercial missions
  - Indirect impact of electrical propulsion on GEO missions → longer transfert time in radiations belts
  - MEO missions (e.g. Galileo)
- New components and instruments
  - Higher integrations
  - More sensitive instruments, low energy level measurement
  - Better taking into account of new materials (dielectric).
- Needs of:
  - A more detailed 3D internal charging analysis
  - Better modeling of the inner charging dynamics

→ Numerous evolutions at the radiations/charging common boundary

→ Evolutions of SPIS required in both numerical model (SPIS-NUM) and IME (SPIS-UI)

→ Require a multi-models and multi-physics approach, in interaction with radiations tools (e.g. GRAS, GEANT-4…)

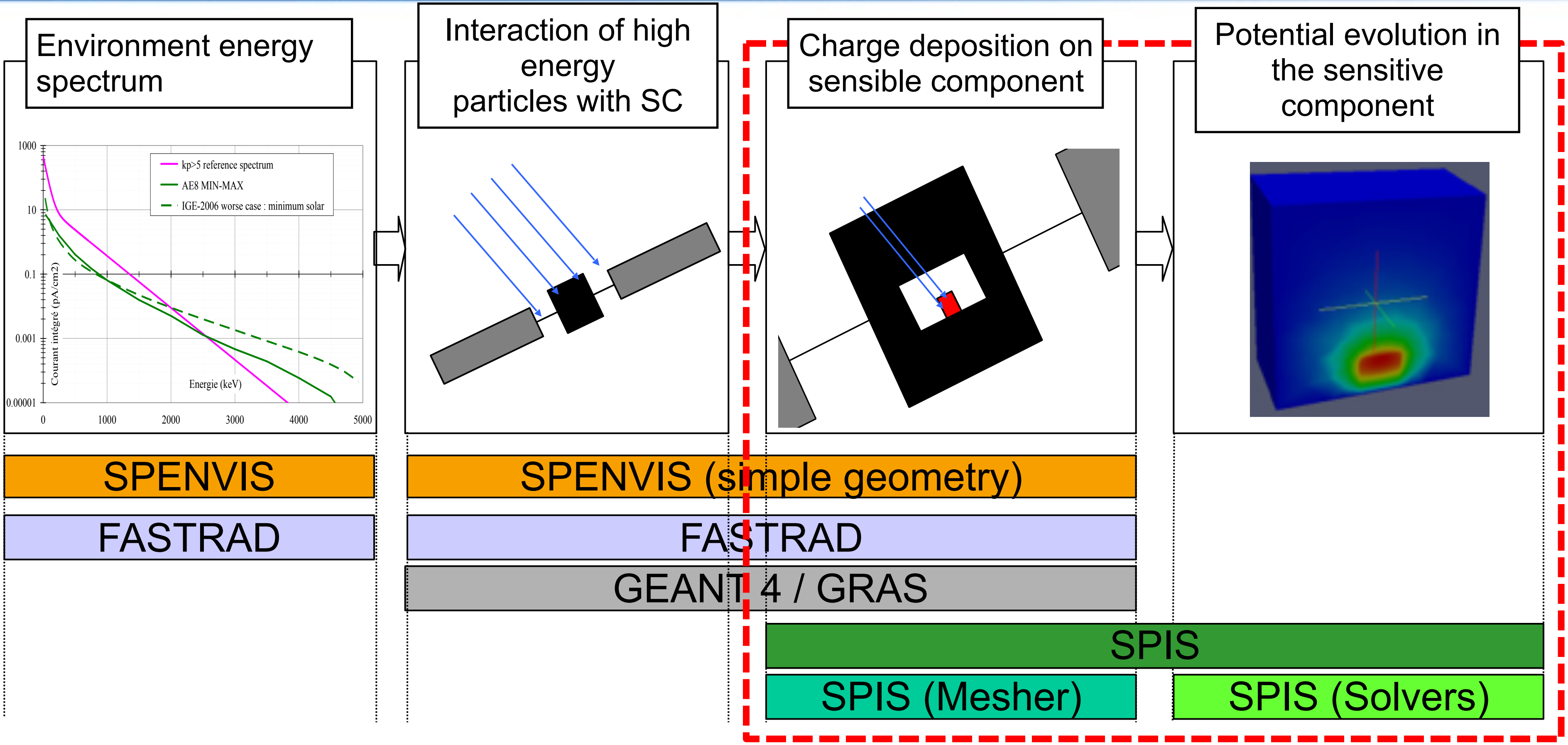
→ Led to a long and structured effort since 2011 and through several projects and actions:

- Several ESA projects:
  - ElShield
  - CIRSOS
  - 3D MICS
- Internal ONERA/Artenum actions: numerical models and IME improvements, GRAS integration, ray-tracing

ELSHIELD – initial project

- ESA/ESTEC contract:
  - Partners: G4AI (Geant4 Associates International Ltd, UK), TRAD (Tests and Radiations, FR), DH Consultancy (BE), ARTENUM (FR), ONERA (FR), TAS-F(F), INTA (SP) ,TAS-E (SP) (Prime).
  - ELSHIELD = Energetic Electron Shielding, Charging and Radiation Effects and Margins
- Develop a tool (or a set of tools) to estimate the cumulative effects of the charge deposition in the S/C payload
- Prevent risk of direct breakdown → margins evaluation
- Use of standard tools:
  - Charging → SPIS (“Spacecraft Plasma Interaction Software”, see http://dev.spis.org/)
  - Radiation → Geant4 based (“toolkit for the simulation of the passage of particles through matter”, see http://www.geant4.org/)

ELSHIELD – Basis of an internal charging tool



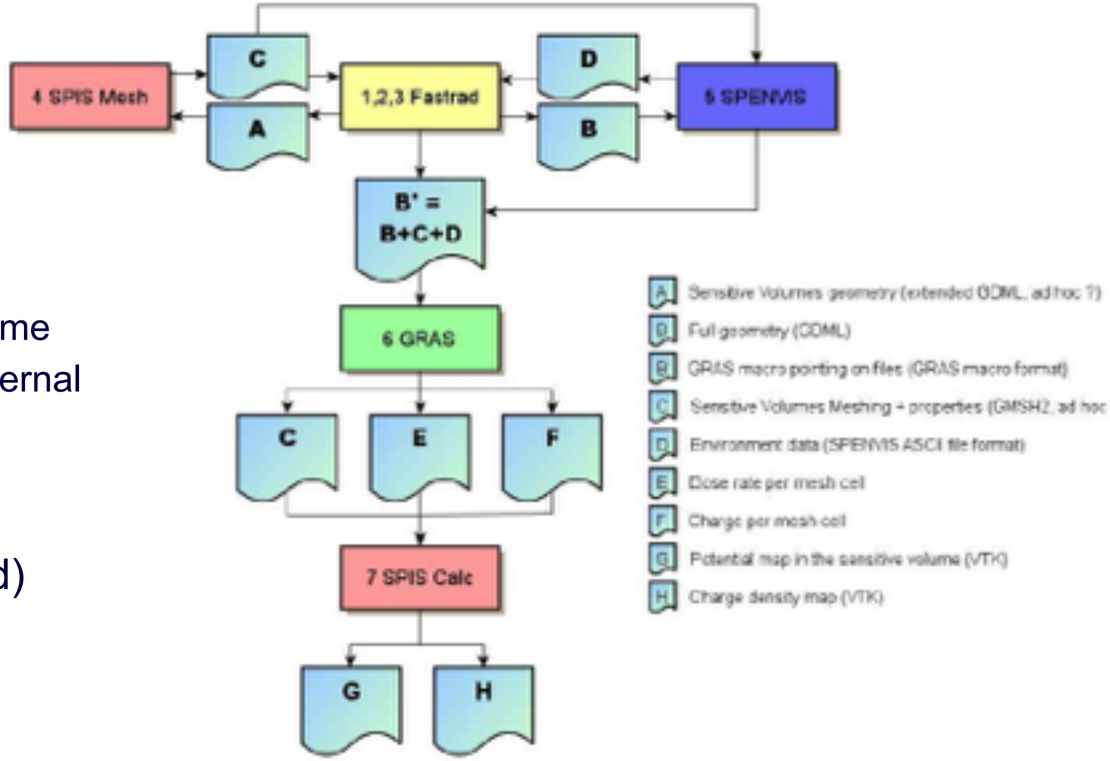
- SPENVIS = Space Environment Information System (see http://www.spenvis.oma.be/intro.php)
- FASTRAD = Radiation engineering tool (see http://www.fastrad.net/)
- GRAS = Geant4 Radiation Analysis for Space (see http://www.geant4.org/geant4/)

ELSHIELD – Interfacing SPIS and GRAS

- SPENVIS and/or FastRad :
  - Environment definition
  - Geant4 geometry definition

- Pre-processing using SPIS :
  - Import the geometry of the sensitive volume
  - Mesh the sensitive volume respecting internal charging constraints
  - Export the mesh to GRAS

- Geant4 simulation (Reverse MC method)



- Internal charging computation in SPIS
  - Import from Geant4/GRAS the charge and the dose deposition
  - Import the simulation parameter from FASTRAD interface
  - Convert the data in a SPIS project
  - Solves electric fields and potential maps in the sensitive area

- Post-processing
  - Export in VTK format dose, charge, electric field and potential as a function of time

Internal charging solvers in SPIS

- Internal charge transport model:
  - Poisson equation
  - Continuity equation for the net charge
  - Ohm's law

$$\begin{cases} -\nabla \bullet (\varepsilon_0 \varepsilon_r \nabla V) = \rho \\ \frac{\partial \rho}{\partial t} + \nabla \bullet J = \dot{\rho} \\ J = \sigma E \end{cases}$$

Charge deposition rate from Geant4/GRAS

- Conductivity model (inspired from DICTAT):

$$\sigma(T, E, \dot{D}) = \sigma(T, E) + \sigma(\dot{D})$$

Dose deposition rate from Geant4/GRAS

- XML material library in SPIS

Material	Density (g/cm³)	Dark conductivity ($\Omega^{-1}m^{-1}$)	Dielectric constant	kp ($\Omega^{-1}m^{-1}$ rads$^{-\Delta}$ s$^{\Delta}$)	Δ	E_A (eV)	Charging hazard
Betacloth	1.05	1.46E-15	3.2	n/s	n/s	2.5	Low
CFRP	1.1	3.11E-13	-	-	-	-	V low
Delrin	1.41	4.41E-14	4	n/s	n/s	1.26	Low
FEP	2.15	2.78E-16	2.91	3.91E-15	0.36	0.25	High
FR-4	2.06	8.48E-16	5.59	1.73E-20	1.07	2.44	High
LDPE	0.92	6.94E-15	4.26	6.97E-14	1.08	1.16	Low
PMMA	1.19	3.05E-17	3.95	n/s	n/s	0.47	High
Polyimide	1.42	1.49E-16	3.01	n/s	n/s	1.75	High
POM	1.41	1.54E-14	3.72	2.07E-13	1.57	1.11	Low
Solithane	0.91	3.56E-14	12.47	1.73E-15	0.57	1.33	Low

CIRSOS

- Key objectives:
  - Improve the integration of the complet modeling process into ONE tool or Integrating Modeling Environment (IME).
    - Simplifying the modeling process for non-experts;
    - Offering remote collaborating and co-expertise capabilities;
    - Centralisation and versioning of modeled systems;
    - Finer radiations/charging models interactions.
  - Provide a tool adapted to future ESA scientific missions, like JUICE, especially in mission definition phase.
- Project gathers 8 partners and leaded by RadMod (See F. Lei for further information)
- Project coordinates at ESA by G. Santin and David Rodgers

Interoperability issues

- At the global modeling process, both ElShield and CIRSOS projects have outlined several sever interoperability constraints:
  - Cross-consistent control of various numerical models (e.g. SPIS, GRAS) and converge control
  - Cross-consistent definition of the computational domain
    - Geometrical description: Not only a question of tools and exchange formats
    - Descriptions needs to be adapted to each model: various LOD, different boundary
  - Material definition and characterization: Attribution and mapping may differ from one model to another one (e.g. nature of the surface in charging).

- Interoperability issues
- Integration issues

3DMICS

- Scope
  - Internal charging critical for mission in MEO orbit and Jovian orbits (JUICE)
  - ELSHIELD development of a first version of SPIS-IC (Internal Charging) tested at the functionality level and on simple cases
  - CIRSOS based on ELSHIELD improving the modelling chain but not the IC physic and solvers
  - IC modeling upgrade requires to take into account the time dependent aspects and more realistic conduction modelling inside the volume

- Objectives
  - Improve the time dependent ability of transport solver and the time evolution of the conductivity
  - Improve the accuracy of the conduction model concerning the dependence on temperature, electric field, dose rate and, accumulated charges and dose
  - Validate the modelling chain by comparing the simulation results to experimental ones

- Method
  - Upgrade the time dependent solver and the conductivity models in SPIS-IC
  - Make available the new modules in the ELSHIELD modelling chain and CIRSOS one
  - Propose and execute IC experiments on ground
  - Compare experimental results to SPIS-IC ones

Perspectives

- Pre-processing improvements needed:
  - Extend to more complex geometries
  - Complex Boolean operation to import Geant4 geometry
  - Extend the automation of the meshing (user intervention required many times)

- 3D Internal charging solver improvement needed:
  - Efficient for the both asymptotic case: large or low time characteristics compared to the simulation duration
    - Solver developments needed for more complex situations
    - Solve implicitly the capacitive coupling in the continuity equation
    - Floating metals, linked to the electrical circuit of SPIS:
  - UI interface improvements (for expert only for the moment)
    - solve implicitly the charging
    - Exact calculation of the floating metal capacitance (Gauss law resolution)
  - Physics and numerical resolution of the interfaces between two different materials

- Data on volume conductivities

Other actions and developments

- Developments done at ONERA/Artenum
  - Developments focused on the charging process
  - In a first time, dedicated to the SPIS-PRO version in support to the SPIS-SERVICES offer
    - Improved models
    - First integration of external radiations tools (GRAS) into SPIS
    - Ray-tracer