PAGER
Just-In-Time charging risk analysis with SPIS in the frame of the H2020/PAGER space weather predictions framework

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Charging Risk Analysis Session

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Prediction of **A**dverse effects of **G**eomagnetic storms and **E**nergetic **R**adiation

- EU H2020 project PAGER (Prediction of Adverse effects of Geomagnetic Storms and Energetic Radiation):
  - **Goal:** Provide space weather predictions initiated from observations on the Sun and predict radiation in space and its effects on satellite infrastructure
  - **Partners:** GFZ (lead), Univ. Warwick, UniV. Michigan, Institute of Space Physics Prague, Artenum
  - **Total budget:** 2.4 Mio €
  - Started in January 2020

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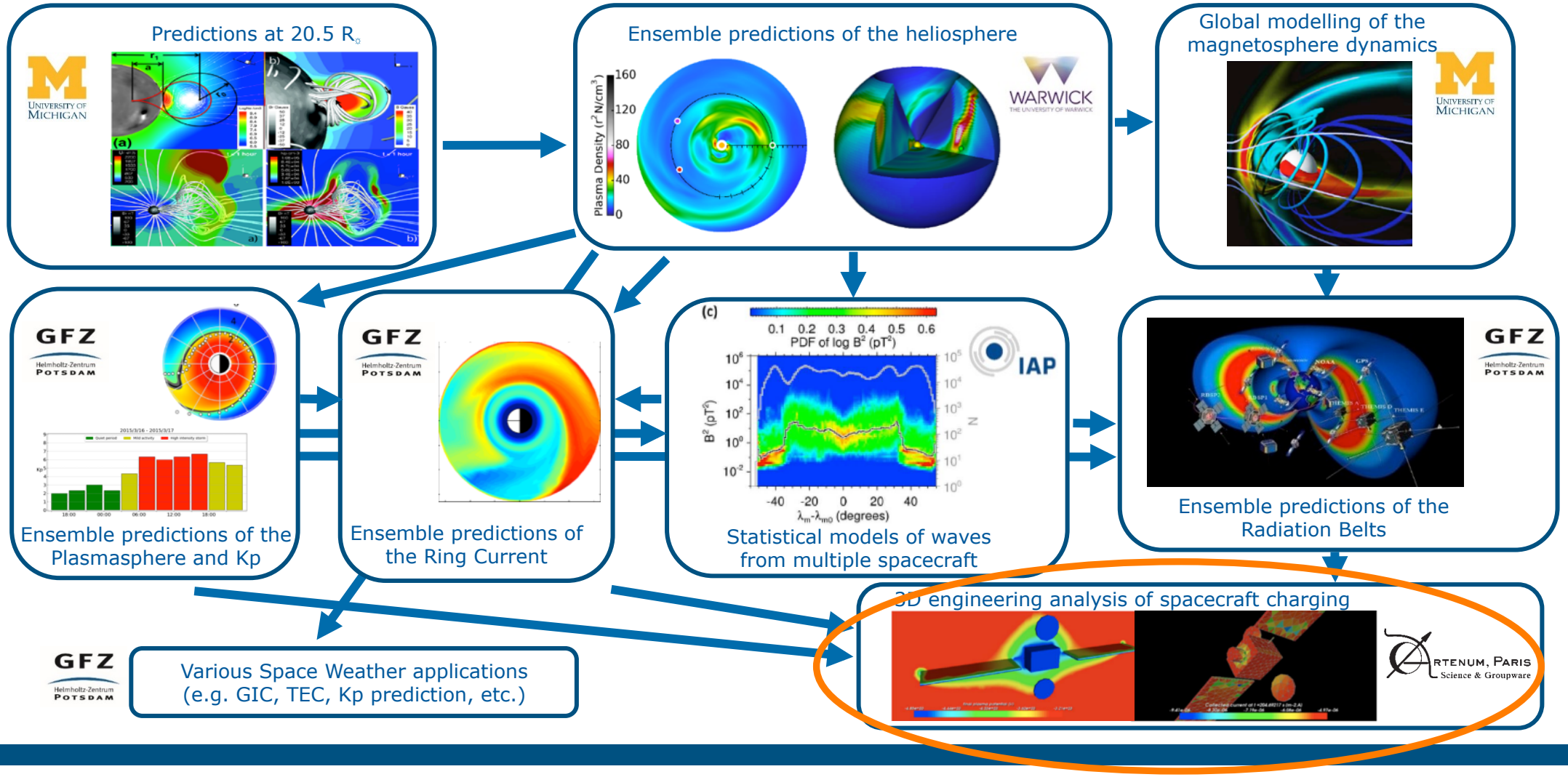
PAGER Aims and objectives

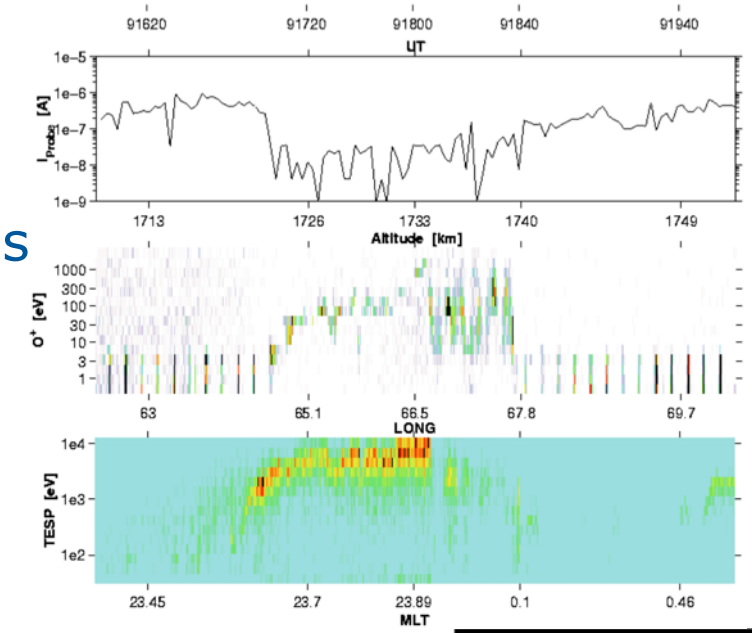
- Environment predictions and forecast
  - Provide space weather predictions initiated from observations on the Sun
  - Predict radiations in space and its effects on satellite infrastructure
  - Real-time predictions and a historical record of the dynamics of the cold plasma density and ring current
  - Predictions of the relativistic electron fluxes
  - Will provide a 1-2 day probabilistic forecast of ring current and radiation belts
- Environment effects risks analysis
  - Evaluation of Surface Charging
  - Evaluation of Internal Charging
  - Provide to satellite operators an “easy to read” and “in advance enough” risk evaluation and significant threats

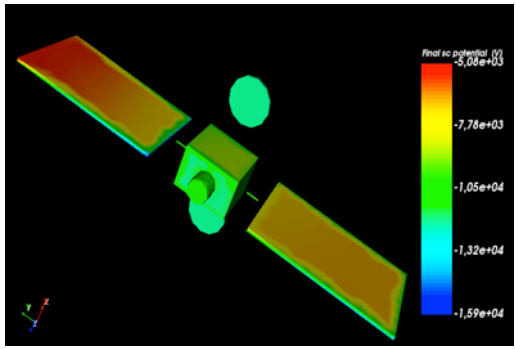
PAGER Global approach

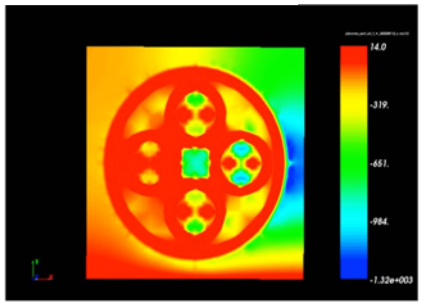


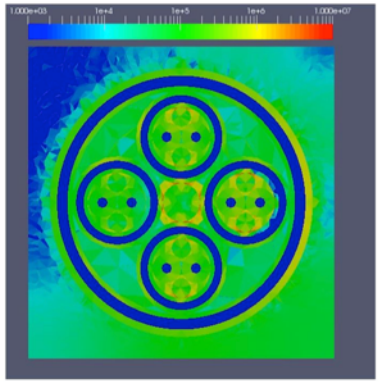
Charging risks and issues

- Surface Charging
  - Absolute potential
    - Perturbation on plasma observations
  - Arcing by differential charging
  - Electrostatic discharge (ESD)
  - Impact on electrical thrusters
- Internal Charging
  - E-field breakdown
  - Dielectric degradation
  - Current leakages







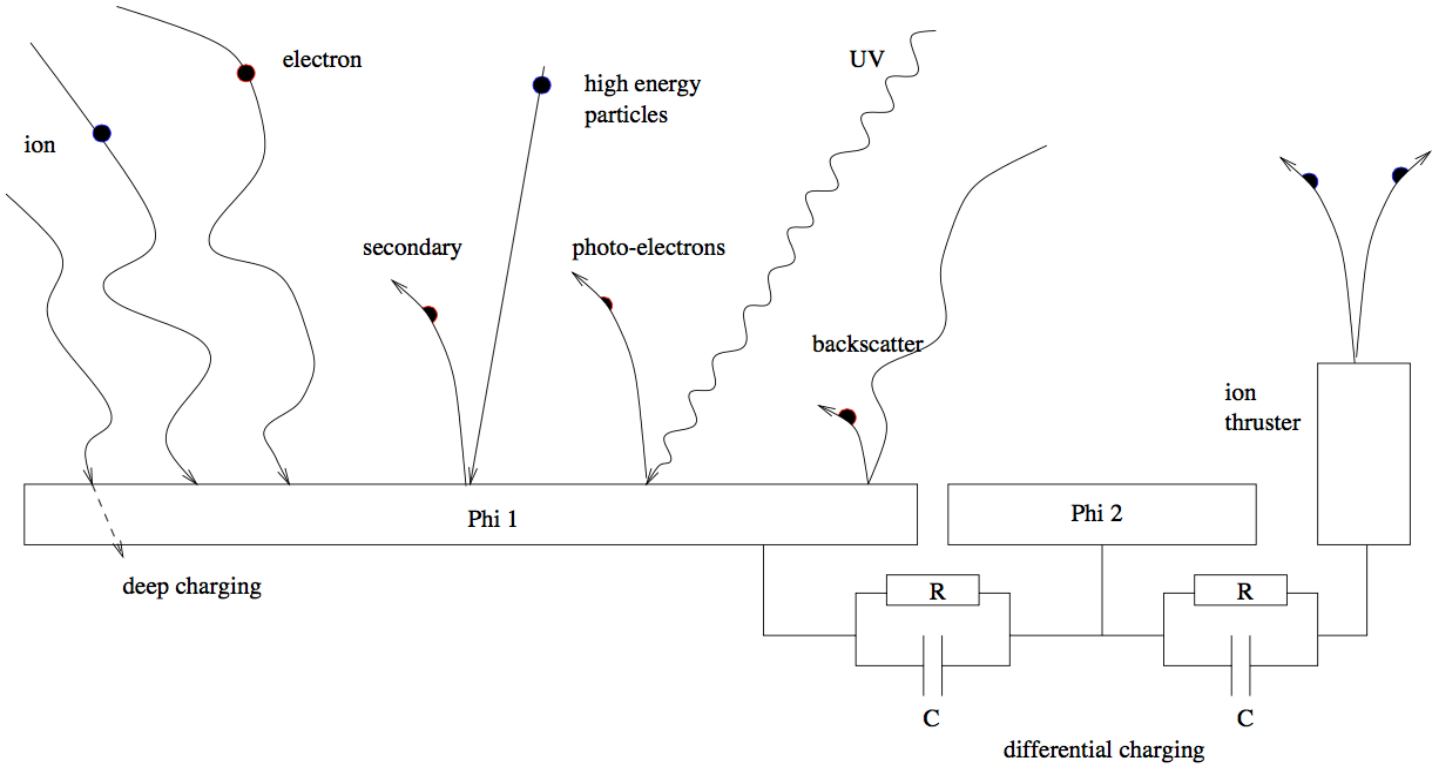


Missions and payloads losses

With courtesies of ONERA/Dephy

Charging Processes

- Surface charging



Typical plasma parameters for LEO and GEO from [29]			
Orbit type	GEO Typical	LEO Low density	LEO High density
Density (m^{-3})	10^6	10^{10}	10^{12}
Temperature (eV)	10^3	0.3	0.1
Debye Length λ_D (m)	235	0.04	0.002
Ion (O^+) Mach number	0.004	6.0	10.0

Minimal range of main physical parameters			
Altitude		1.5 R_e	8 R_e
Larmor radius (gyro-radius)	electron	20 m	7.10^8 m
	proton	1 m	7.10^8
Energy		0.01 eV	100 keV

Charging Processes

- Internal charging

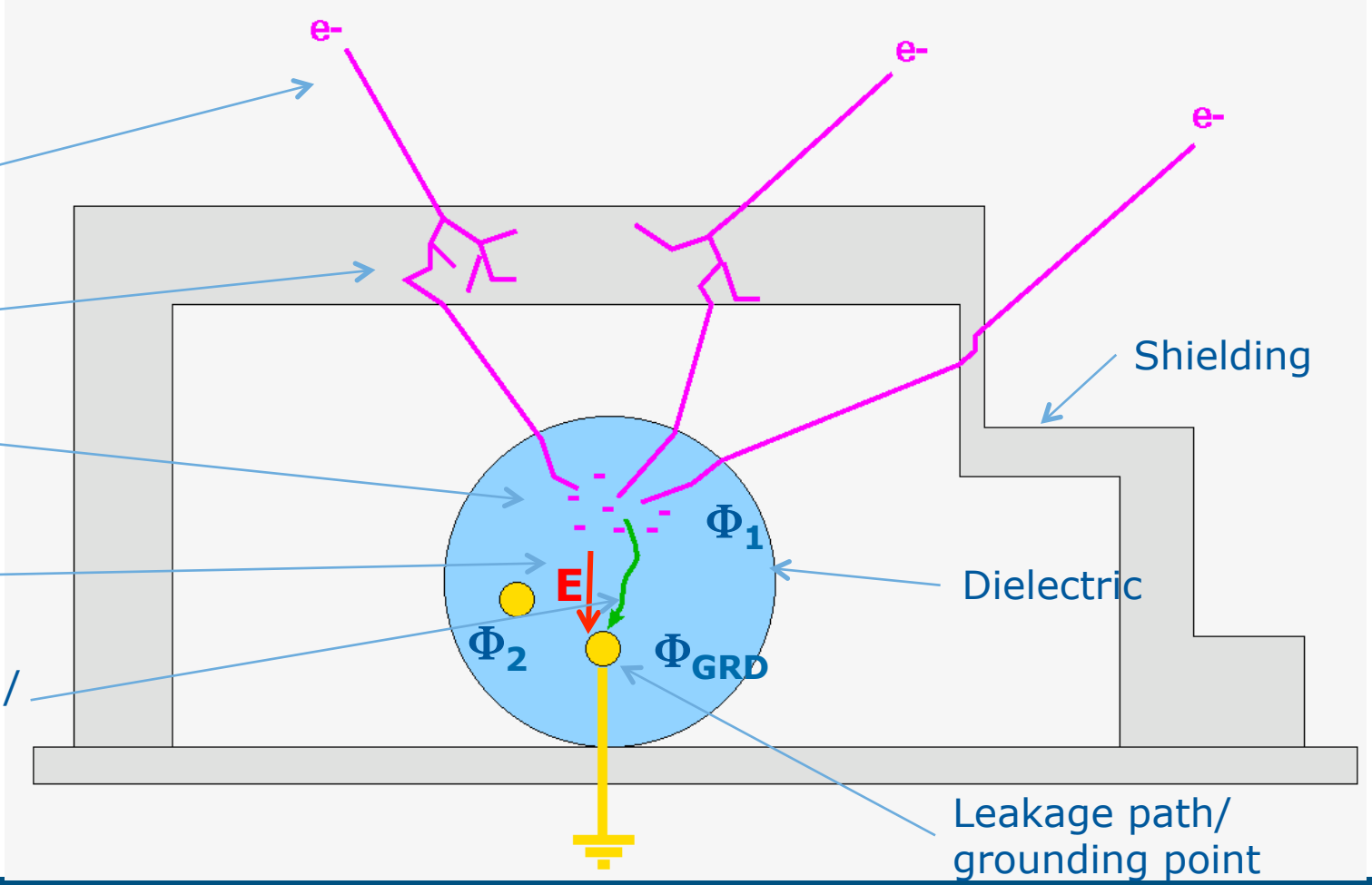
Environment models (primary energy particles fluxes/ fluencies)

Transport model

Primary deposited charges and dose rate

Electrical field and possible breakdown

Charges migration / current density

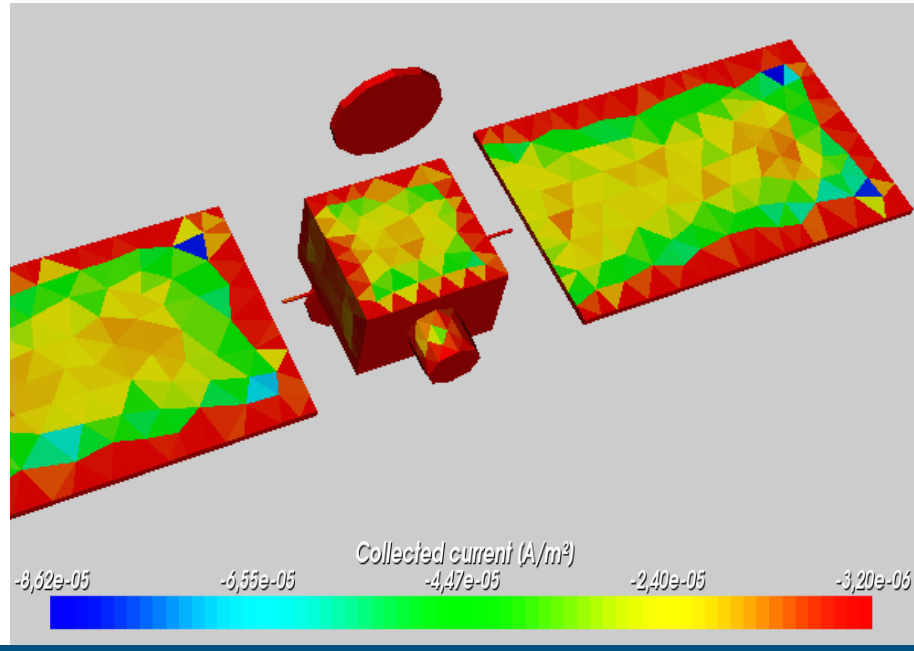


Limits of existing approaches and constraints

- Existing online models
  - Up to now, no so such advanced integration of charging models (as effect model) downstream to environment / forecasting ones
  - Most of existing/past implementations remained limited to
    - Simple geometries and continuous environmental conditions (e.g. DICTAT)
    - Asymptotic plasma conditions (e.g. analytical Langmuir's probe models)
    - Difficulties to model complex and dynamical conditions characteristics of weather events
    - Difficulties to model complex and realistic modern missions
  - Requires a multi-model and multiscale approach

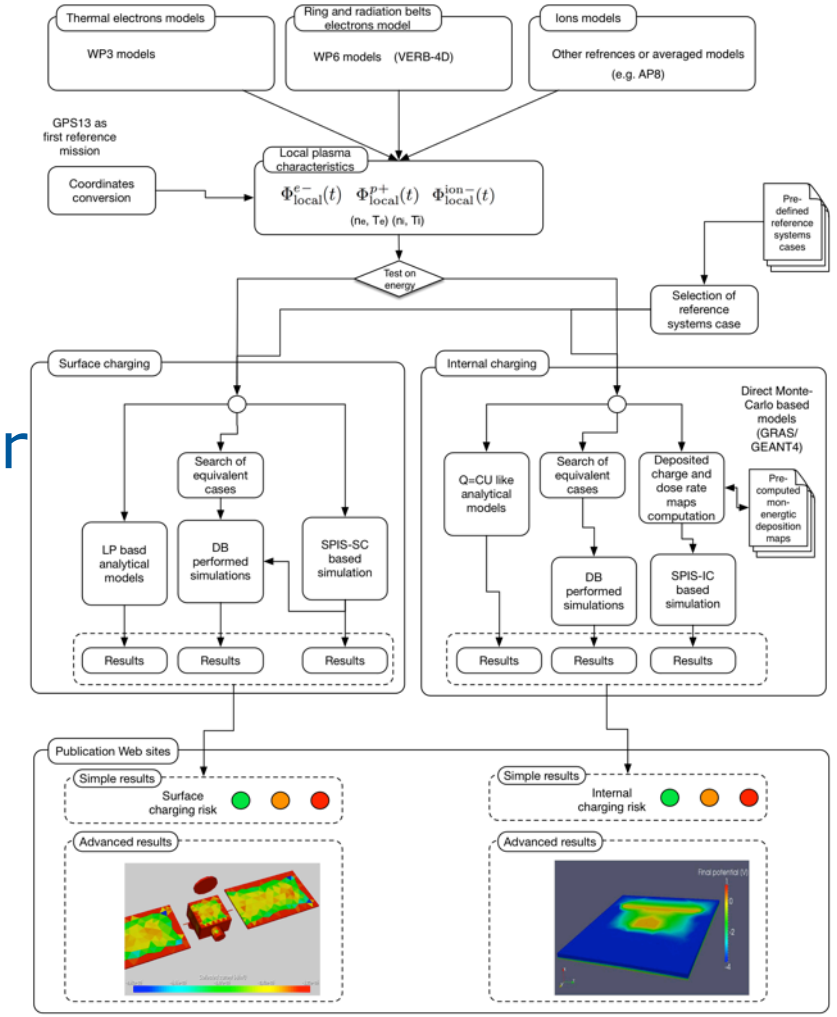
PAGER's objectives: Modelling of effects on space structures and charging risk evaluations

- Key objectives: Integration of charging models downstream to environment ones
  - Provide a "real time" evaluation of the charging risk in function of the forecasted space weather
    - Surface charging
    - Internal charging
  - Online (Web frontal) simple indicator (i.e. green/orange/red flags)
  - Proposition of mitigations strategies
- Use advanced 3D charging models, like SPIS-SC and SPIS-IC

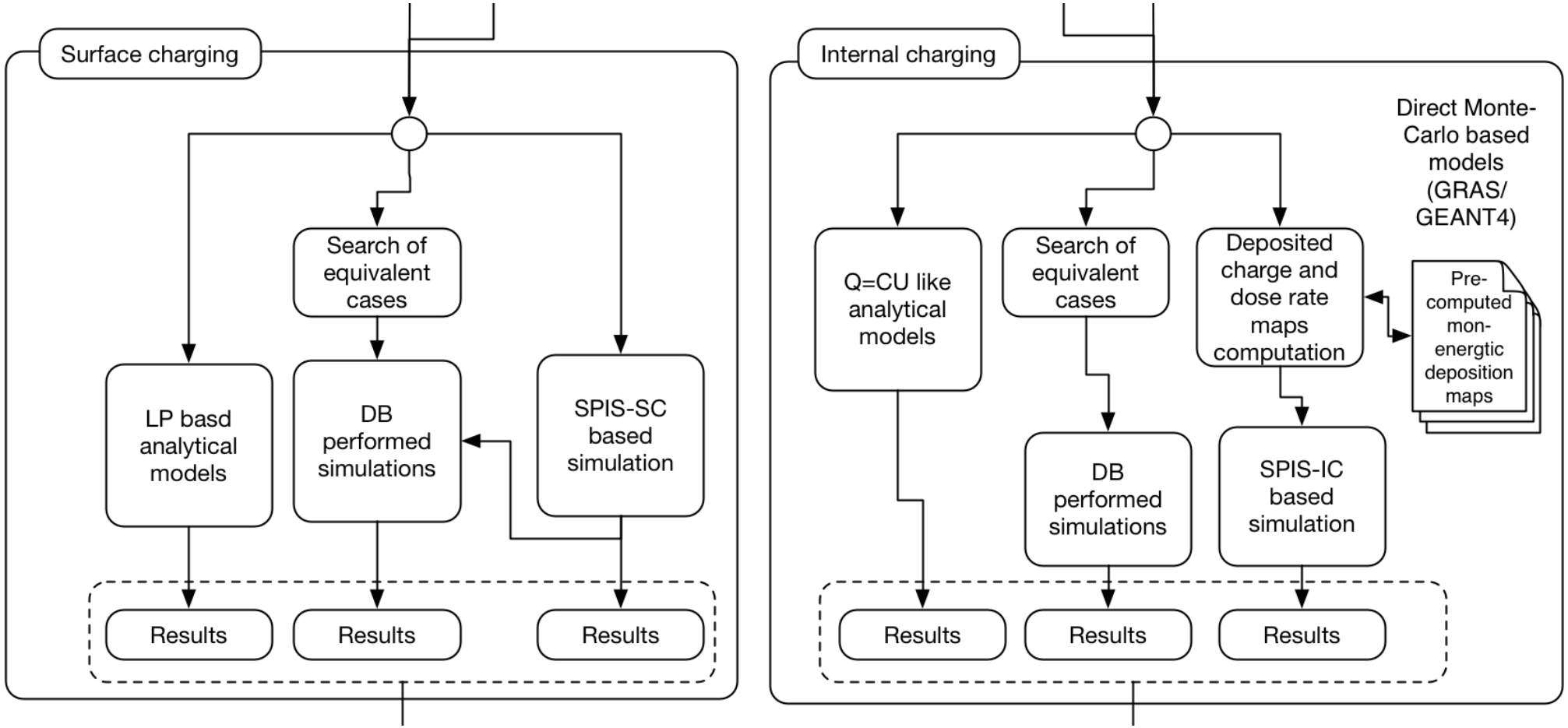


Charging Analysis: Proposed Approach

- Three orbit types missions targeted:
  - GEO (e.g. GOES mission)
  - MEO (e.g. Galileo, GPS)
  - LEO/Polar (Earth observation and future massive constellations)
- Targeted update rate about 2 updates/hour with a mix of:
  - Simplified analytical models
  - <u>SPIS based 3D dynamical simulations</u>
    - Systems cases simple enough to be run in a few minutes
    - Relevant for typical sensitive systems.
  - Progressive building-up of a set of simulation results (database) for faster further analysis

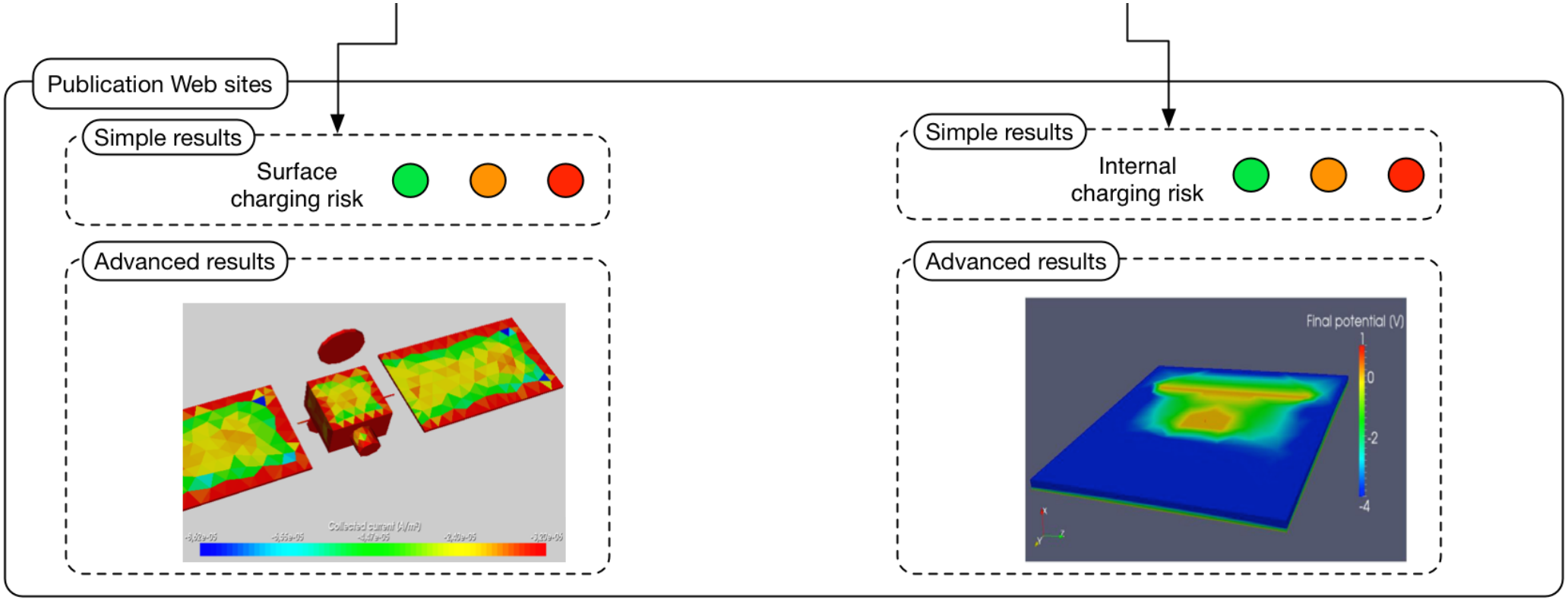


Charging Analysis: Proposed Approach



Charging Analysis: Proposed Approach

Online publication



Relevance of the effects models

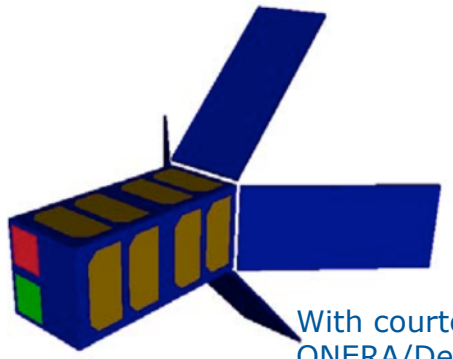
- The risk depends on the studied system as well
  - A same environment may have not the same impact on different platforms or payload
- Necessity to identify relevant or normalised cases
  - Relevant for the largest scope targeted missions
  - Compliant with used models (i.e. simple enough to be run "just-in-time)

The same sea state has not the same impact on all ships.

Reference cases

- Surface charging
  - LEO/Polar/MEO
    - Simple or double sphere, as “worst case”
    - Simplified cubsat (e.g. ONERA /CROCUS mission)
  - GEO
    - Simple or double sphere, as “worst case”
    - Simplified realistic platform (Davis case)

- Internal charging
  - All orbits
    - Coaxial cable outside the S/C shielding
    - Sub-D connectors
    - Simplified PCB card
    - Matrix detector



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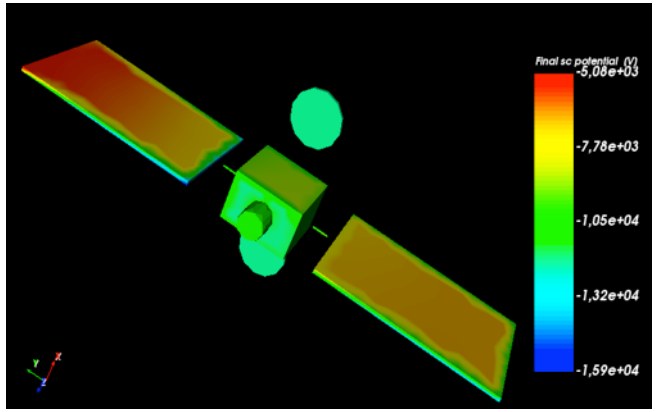

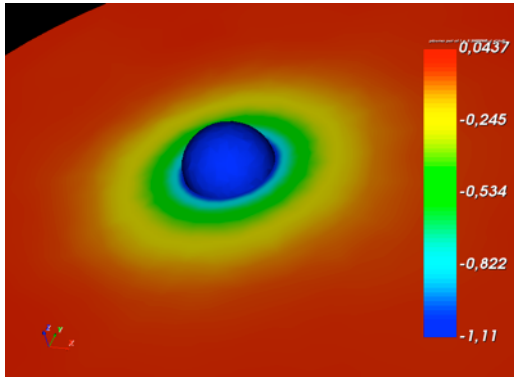

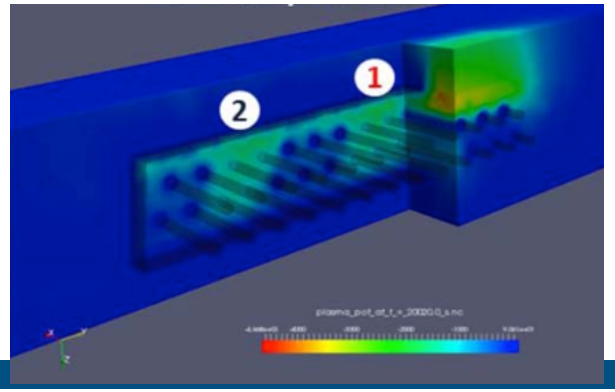

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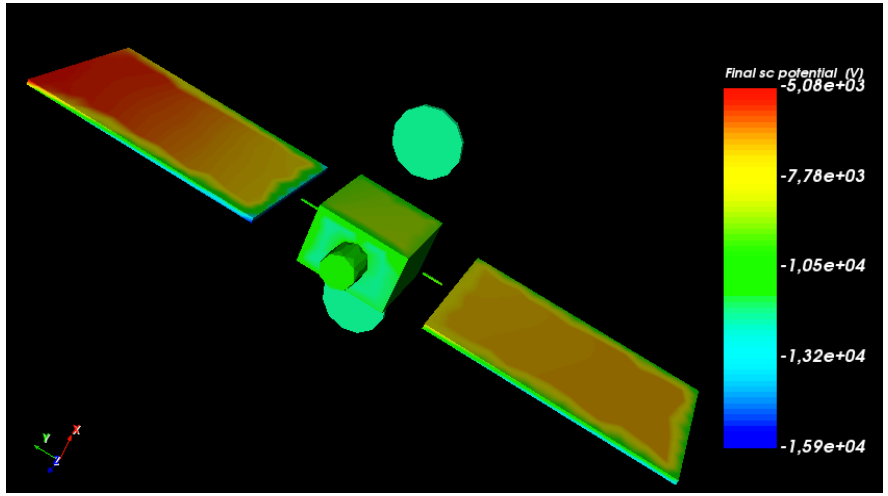
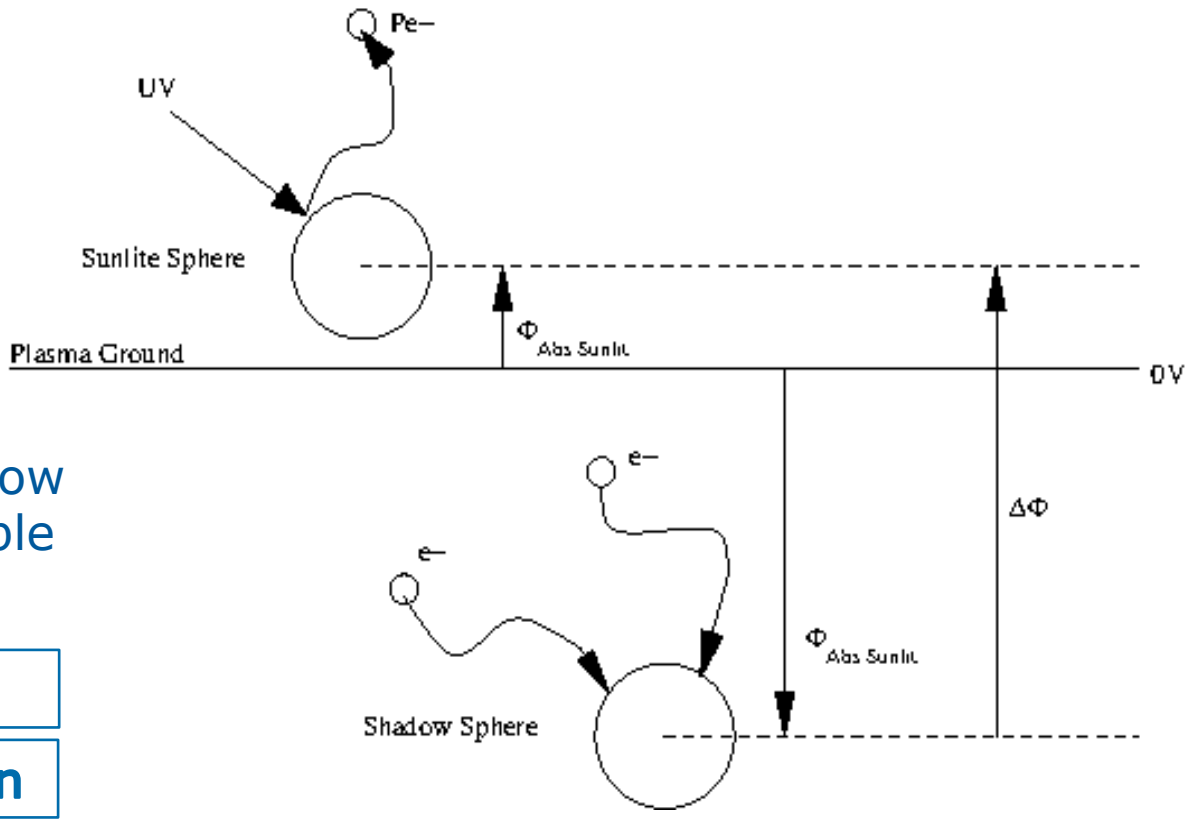
Reference cases





In GEO, floating potential of sphere in shadow as rough estimation of the maximum possible differential charging (worst case).

Rapid convergence, fast computation

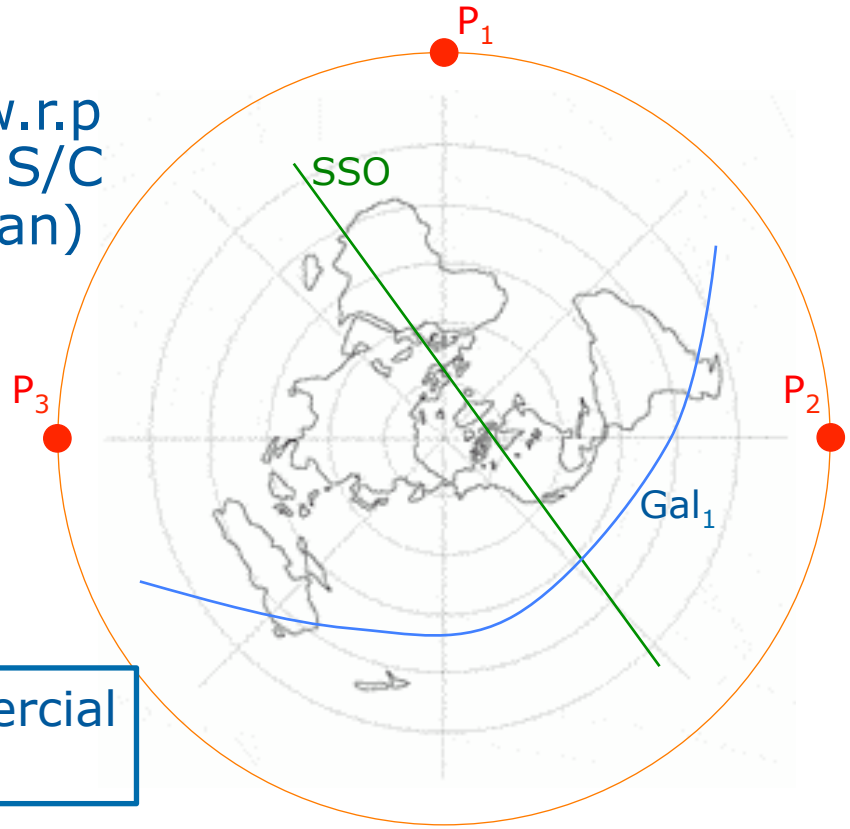
Reliable and quick first risk evaluation

Where and when evaluate the risk?

- Dependent on local plasma conditions and particles fluxes
- Need to pass from environment maps to local condition
  - Orbit systems conversion
- Potentially dependent on the mission profile (e.g. GEO/MEO/LEO)
- Potentially dependent on the mission history
- Several times (i.e. Day_0+1, Day_0+2…) for each forecast
- <u>Need to find an equilibrated balance between the total number of simulation points and the CPU cost</u>

Where and when evaluate the risk?

- Need to simplify / select key orbits/positions
  - GEO
    - Selection of a few key of relevant fixes positions w.r.p to the Earth surface where numerous commercial S/C are located nearby (e.g. one on Greenwich meridian)
  - MEO/LEO
    - One arbitrary SSO orbit
      - Flyovers in the polar regions
    - One Galileo or GPS orbit
      - Pass through the radiations belts



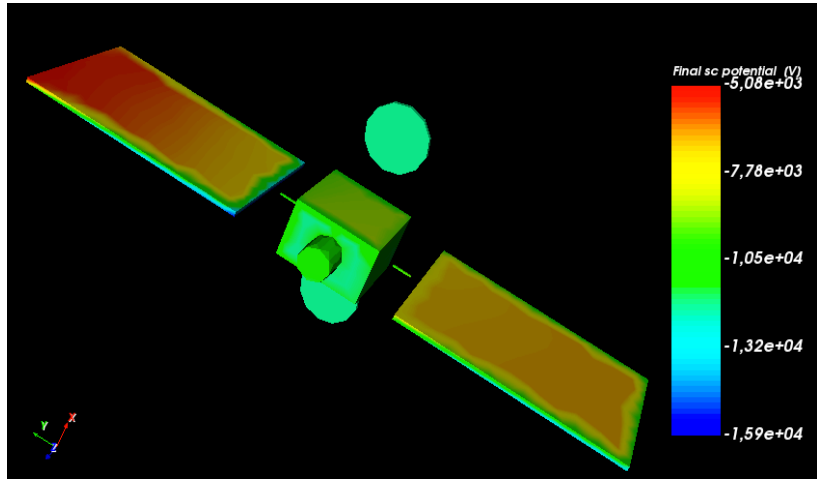
Should address the needs/constraints of most of commercial missions, with a reasonable CPU cost.

Surface charging approach

- Surface charging
  - Quite rapid process
  - Environment punctually assumed as quasi-static from the charging analysis point of view
  - “Simple” charging analysis, but require to select the relevant model
- Proposed approach
  - Mainly use a SPIS based 3D simulations on the preconfigured reference charging cases
  - Completed by analytical Langmuir’s probes like models

Surface charging: Code testing and CPU time evaluations

- Several reference cases already successfully tested with SPIS-SC
  - Realistic cases in GEO (GEO.SURF.004) can be run in about 15 minutes on a mid-size worstation
  - Simple small sphere in a few minutes in GEO and about one hour in LEO and full PIC
- Confirm that a numerical based approach using SPIS-GEO seems reachable and sustainable in operational phase
- However the LEO and Polar orbits remains challenging and cannot be guaranteed yet.



Internal charging approach

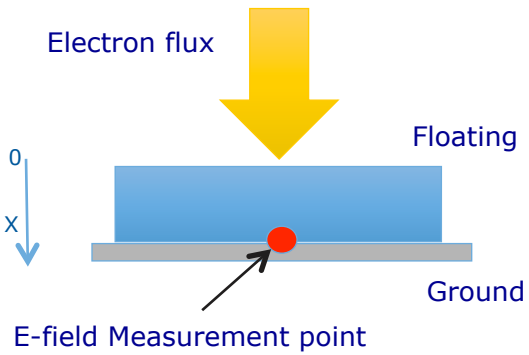
- Long-term process
  - Environment cannot be assumed as quasi-static during the charging/discharging process
  - Necessity to take into account the history of the dose/charge rate
    - Sliding window long enough to integrate the whole long term charge
    - Update rate high enough to handle environmental variations

Internal charging approach

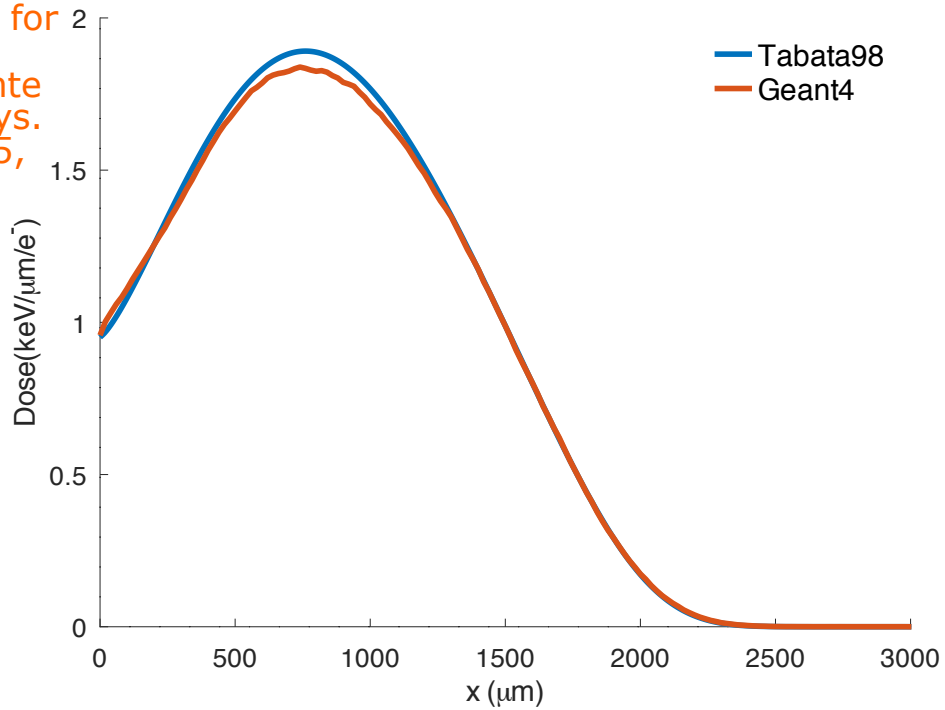
- An approach in several steps is needed:
  - Characterisation of the transport through the shielding (e.g. Monte-Carlo model) beforehand the operational phase
  - Dynamically update the received fluxes according the environment variations and the shielding transfer function
  - Perform the 3D internal charging analysis in a dynamic way typically using SPIS-IC
- Two modelling chains considered
  - 3D SPIS-IC based approach for fine results
    - See Hector Balboa's presentation: Time-dependent electron environment effect on the internal charging dynamics by SPIS-IC simulations
  - Simplified 1D analytical model for quick first answer in complement

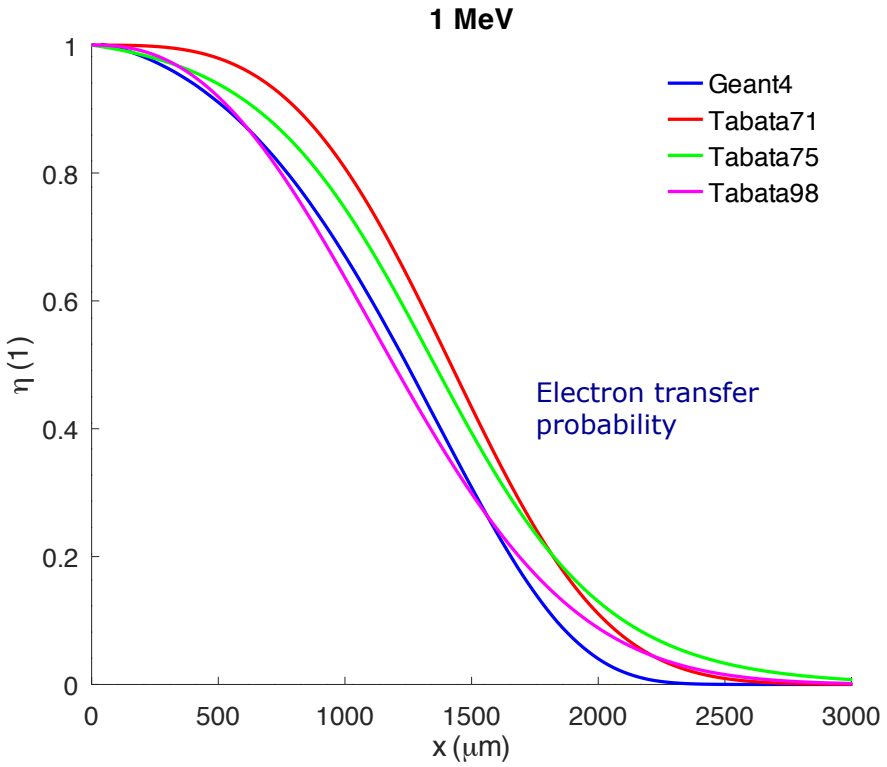
1D alternative internal charging model

- Simplified 1D analytic model
- Dose and charge rates
  - T. Tabata, P. Andreo and K. Shinoda, An Algorithm for Depth-Dose Curves of Electrons Fitted to Monte Carlo Data, Radiat. Phys. Chem., 53, pp 205-215, 1998 Charging model
  - Ohm's law



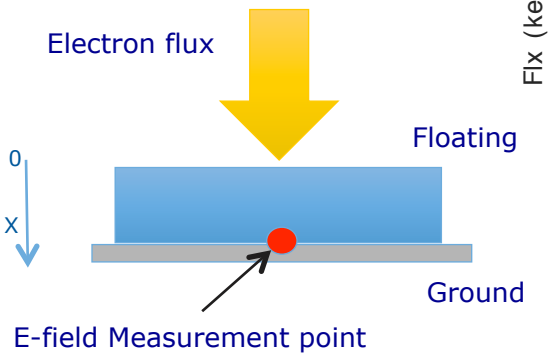
- First tests and validation

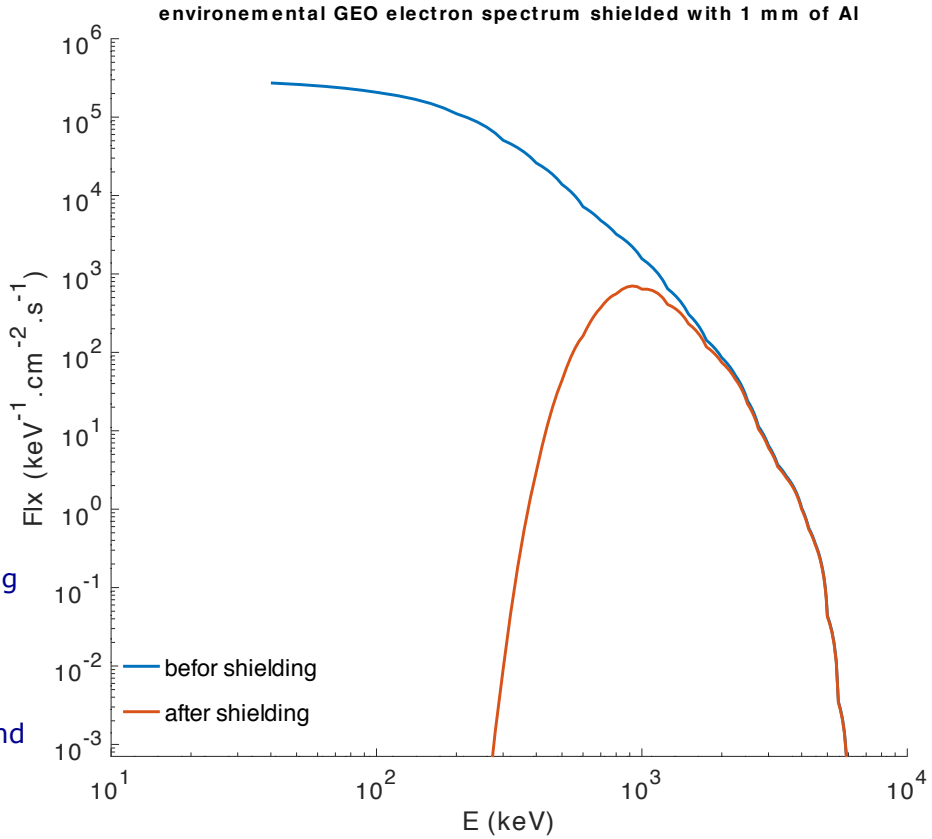




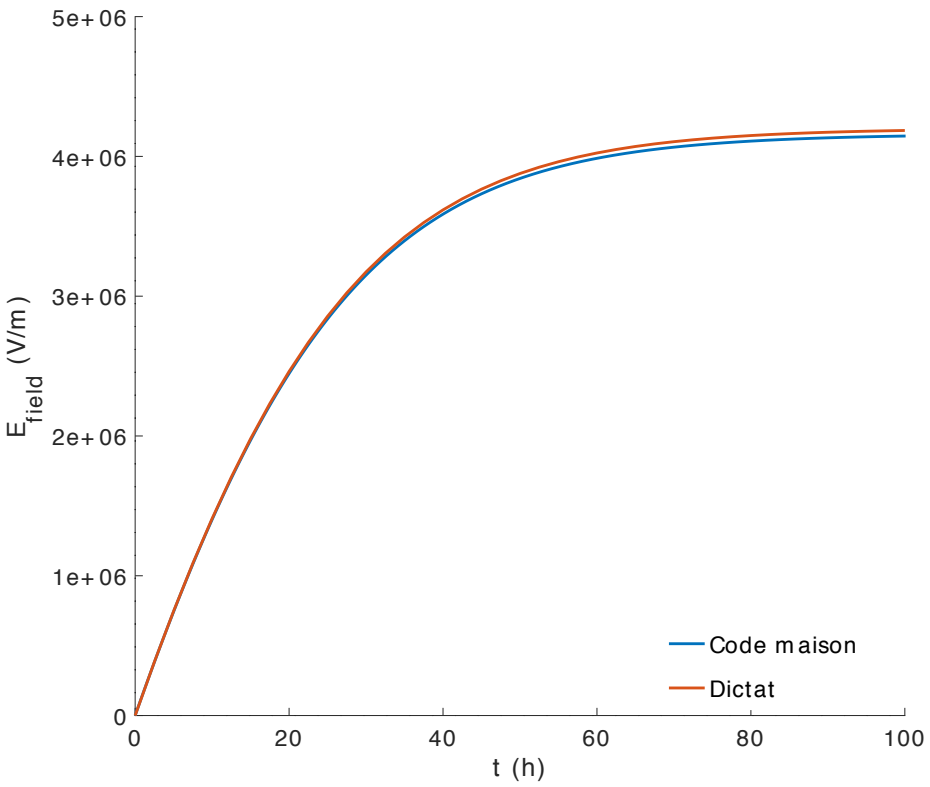
Internal charging and first tests

- Spectrum after shielding





- Comparison against DICTAT



Conclusion

- H2020/PAGER project objectives
  - Gather environment prediction models and charging analysis ones
  - Provide an « easy to read » charging risk prediction for both surface and internal charging
  - Based on rich plasma/matter interactions 3D models and the integration of SPIS-SC/IC
- Work still under progress, but first results are already here:
  - The different modelling chains are identified
  - The reference charging cases are identified
  - Most of low-level charging models are implemented (i.e. SPIS-SC/IC, 1D analytical models)
  - In spite the urban legend, in most of the cases and with proper configuration, SPIS is fast enough to perform simulations fast enough in operational phase, i.e. SPIS can be used for spaceweather effects forecast.
  - Additional analytical 1D models implemented to complete the framework and guaranty fast results
  - Service currently under implementation / integration
- Contacts and further information
  - Visit the Project's Web site
  - PAGER related questions / information:
    - Yuri Shprits (GFZ, Project Manager)
    - Melanie Burns (GFZ, Coordinator, melanie.burns _at_ gfz-potsdam.de
  - Charging analysis models and service
    - Arnaud Trouche (trouche _at_ artenum.com)
    - Benoit Tézenas de Montcel (tezenas-du-montce _at_ artenum.com

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