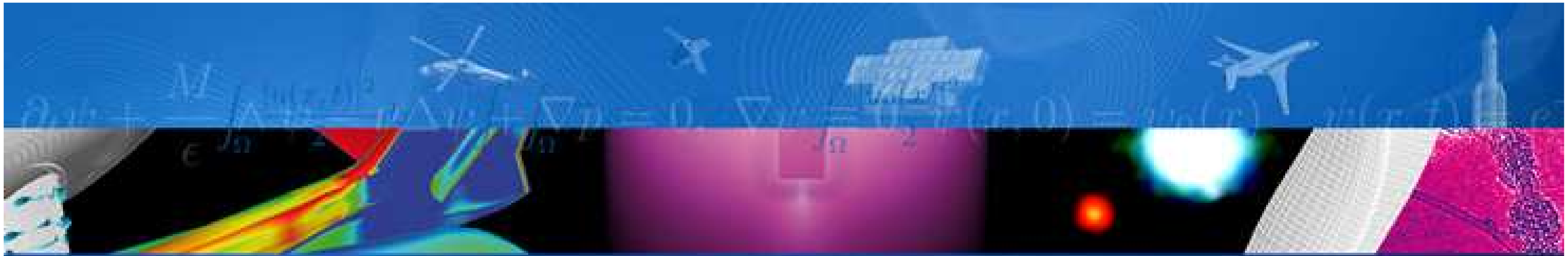


SPIS status

SPINE Workshop, March 7, 2012

ONERA

THE FRENCH AEROSPACE LAB

retour sur innovation

SPIS context and project overview

- SPINE (Spacecraft Plasma Interaction Network in Europe) community setup around year 2000 (A. Hilgers, J. Forest, JF Roussel...):
  - An idea was born: gather European efforts for SC-plasma interactions
  - Exchange: knowledge, data, codes, results...
  - Boost the development of a common simulation toolkit: ESA ITT in 2002 => SPIS
- SPIS Development (Spacecraft Plasma Interaction Software) :
  - Initial development: 2002 – 2005
    - ONERA-Artenum consortium
    - ESA/ESTEC TRP contract
- Solver enhancement: 2006 – 2009
    - Mostly ONERA
    - ESTEC ARTES contract, French funding
- Other
  - Some community developments
  - Some CNES-funded enhancements (EP, ESD)
  - ESD triggering modelling (ESA TRP) 2010
- 2011 : SPIS version 4.3.1

SPIS on-going activities

- at ONERA and ARTENUM
  - SPIS-SCIENCE
    - Development of a "Computational tools for spacecraft electrostatic cleanliness and payload accommodation analysis
    - Next slides
  - SPIS DC-Deep Charging
    - Development of an Internal Charging solver in the frame of the ELSHIELD project
    - Presentation by P. Sarrailh (ONERA)
  - SPIS-GEO
    - Development of a "Simplified Standard MEO/GEO Tools for Spacecraft Charging"
    - Presentation by J. Forest (ARTENUM)
  - SPIS-Maintenance (ESA TRP)
    - "Winter School" on SPIS use
      - in conjunction with this SPINE WS
      - 2 training sessions of 10-12 students (1st one was yesterday; next is tomorrow !)
    - Definition of non regression procedure : ~10 "basic" spis test cases provided to the community
- And also
  - SPIS-PROPU
    - Improvements in SPIS in the frame of AISEPS
    - Presentation by M.Wartelski (Astrium F)

SPIS-SCIENCE progress

SPINE Workshop, March 7, 2012

ONERA :	J.-C. Matéo-Vélez, P. Sarrailh, J.-F. Roussel
ARTENUM :	J. Forest, B. Thiébault, B. Ruard
IRF :	A. Eriksson
IRAP :	V. Génot
ESA:	A. Hilgers

ONERA

THE FRENCH AEROSPACE LAB

retour sur innovation

Outline

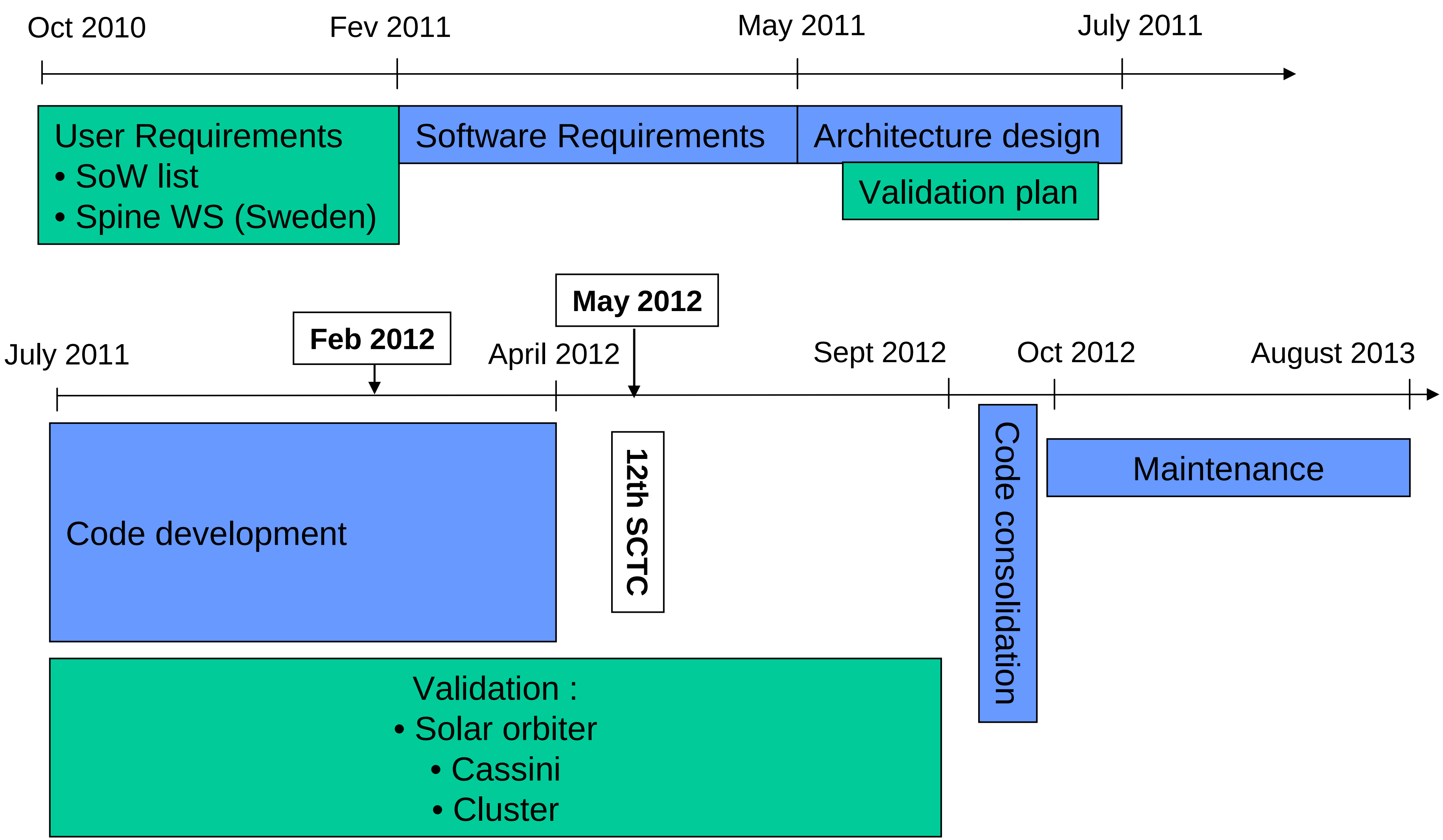
- Overview of the activity
  - Scope
  - Objectives
- Work progress
  - User requirement from scientific community for missions modeling
  - SPIS-SCIENCE tool
    - Overview of main features
    - Some details on progress and work to be performed
  - Validation campaign
- Summary

Overview of the activity

- Scope
  - ESA/ESTEC contract 4000102091/10/NL/AS
    - Technical Officer: Alain Hilgers
    - Partners: ONERA, ARTENUM, IRAP, IRFU
  - Long-term scientific program of ESA has planned missions dealing with plasma measurements
    - Solar Orbiter, Juice (Jupiter)
    - Relatively low energy (few eV) plasma measurements
    - Electrostatic cleanliness becomes very important
- Objectives
  - Provide a computational tool able to predict quantitatively
    - The charging of a S/C
    - The space charge in its environment
    - Their consequences in low energy plasma measurements
  - Outputs for the user (= scientific community)
    - New version of SPIS software
    - Validation test cases related to the scientific mission conditions
    - One year maintenance

Work progress

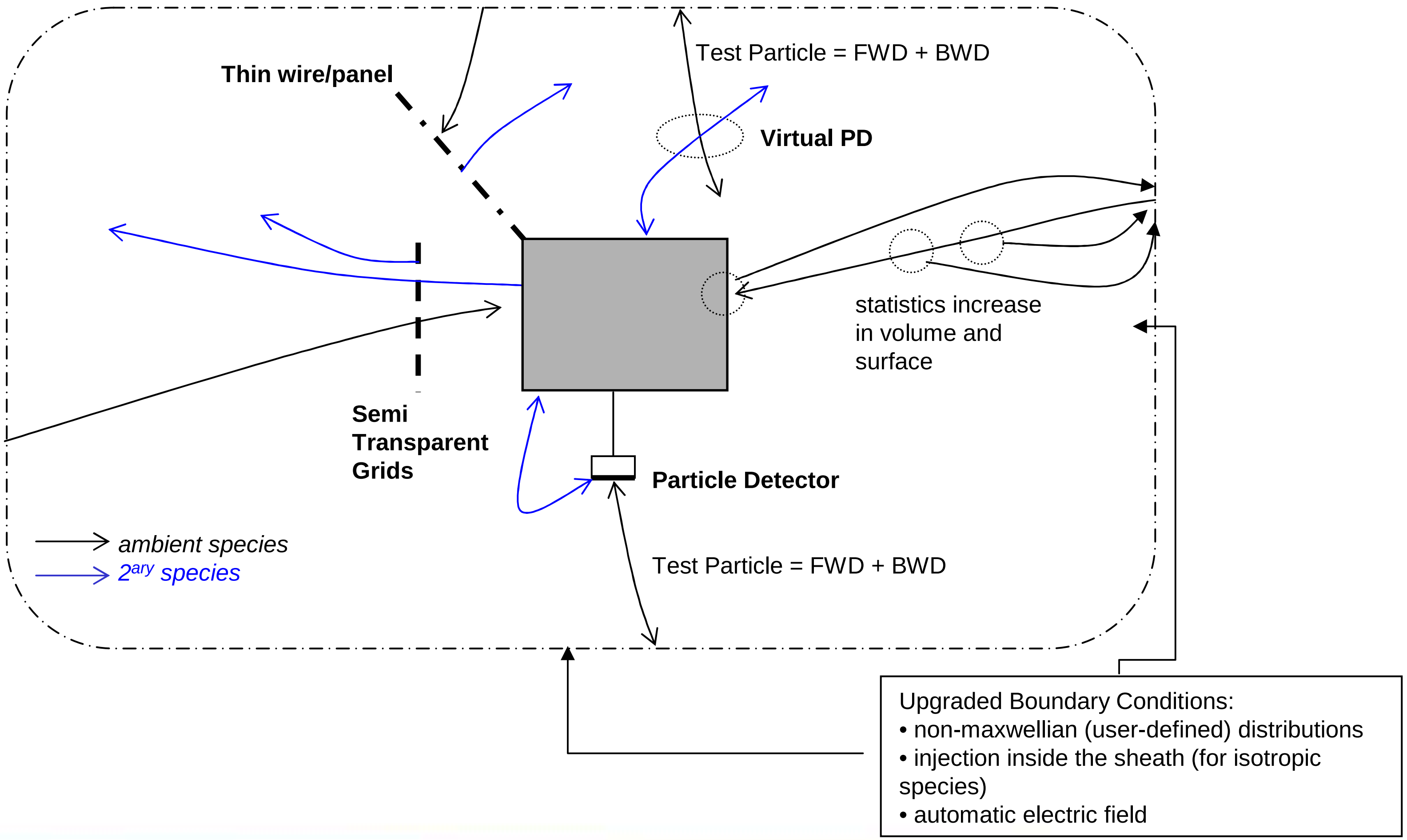
ONERA/ARTENUM
IRAP/IRFU



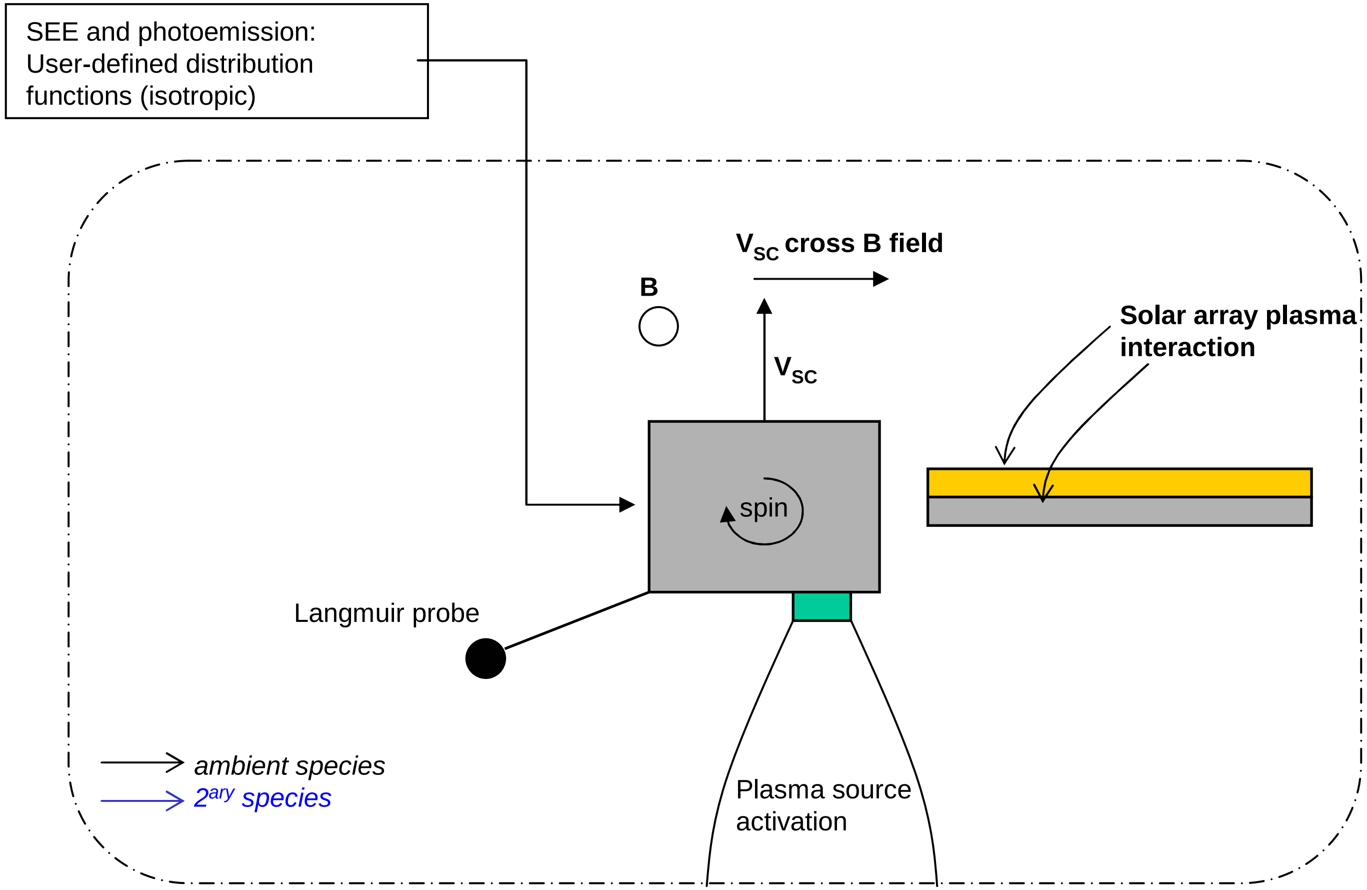
Scientific missions modeling – User requirements

- User requirements for an upgraded SPIS
  - From past experience of ESA and consortium
  - Organization of a SPINE WS at Uppsala, Jan 2011, to collect UR from the relevant science community
    - ~ 50 attendees from scientific univ. or instit., space industry, agencies
    - ~ 25 presentations
    - Plasma physics modeling, particle and plasma instruments, flight measurements, mission needs, SPIS use and limitations …
  - Exhaustive and not limited user requirements list
  - Detailed requirements on phenomena modeling

Work in progress



Work in progress



Distribution functions

- Only bi-Maxwellian environment in Spis 4.3.1

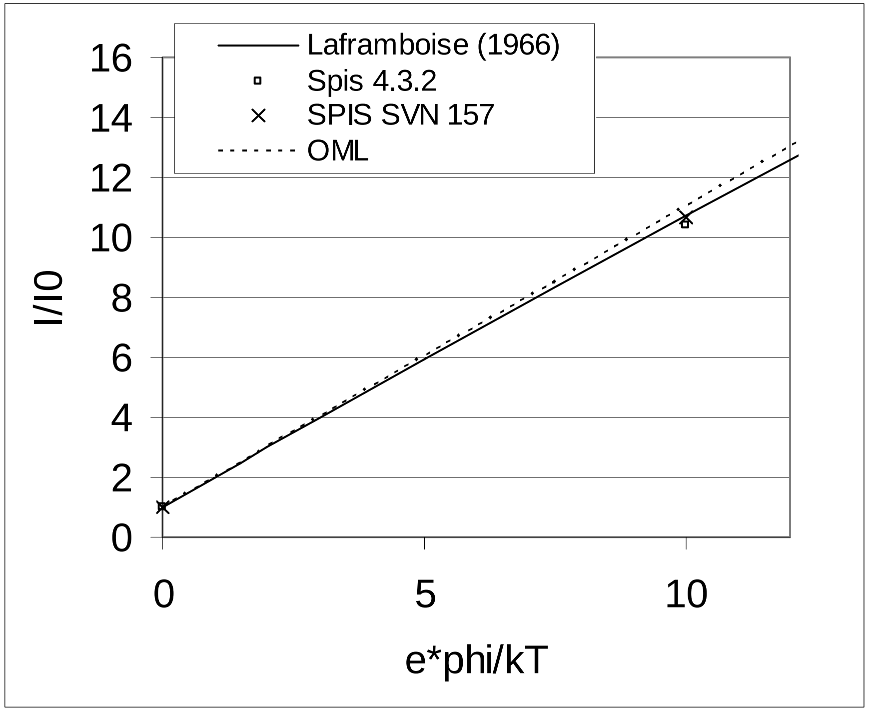
- Work progress : Generic distribution functions
  - Generic 3D sampler and isotropic samplers
  - **User-defined df : tabulated files**
  - Analytical laws can also be implemented

- Work to be performed
  - Implement analytical df: kappa, drifting maxwellian for ambient
  - Implement user-defined isotropic df for secondary electron emission and photoemission process

Boundary conditions

- Upgrade of particle injection
  - Non-zero electrical potential at external boundaries → disturbed plasma → change of the injected distribution function
  - Validation: better accuracy in the case of a spherical probe immersed in maxwellian plasma (error<1% instead of 3-5 % in previous version))

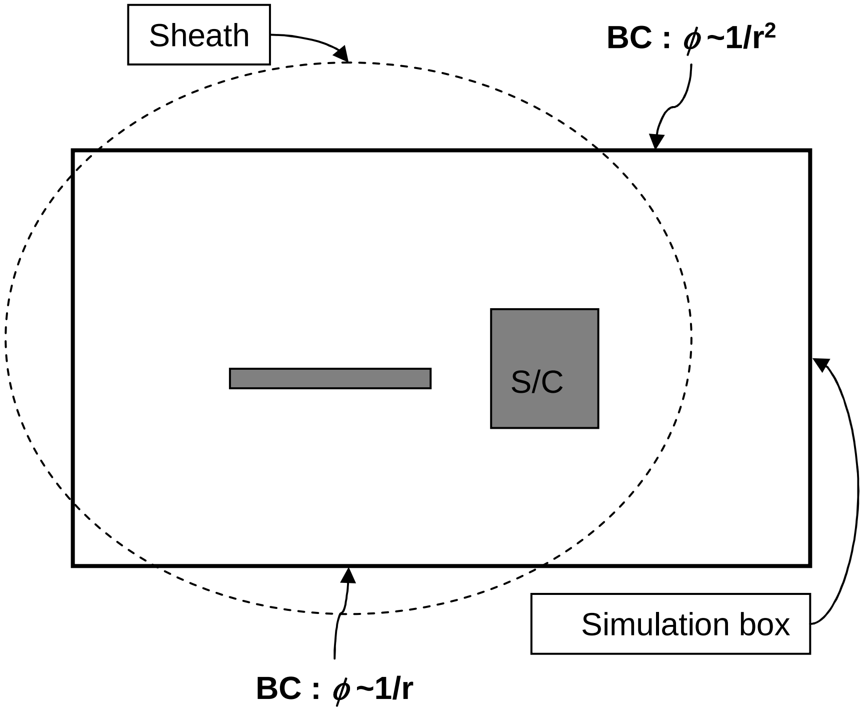
Quantity	Value
Temperature	0.5 eV
Electron/ion density	$6{,}91\times10^8$ #/m3
Debye length	0.2 m
Potential	[0-5 V]
Sphere radius	0.1 m
Number of tetrahedrons	~42,000
Simulation box diameter	1.0 m
Number of macro-particles	~500,000



ONERA

Boundary conditions

- Electrical potential
  - Automatic and local shift between two regimes
  - If the external box is outside the sheath : pre-sheath model $\phi \sim 1/r^2$
  - Else : vacuum-like condition $\phi \sim 1/r$

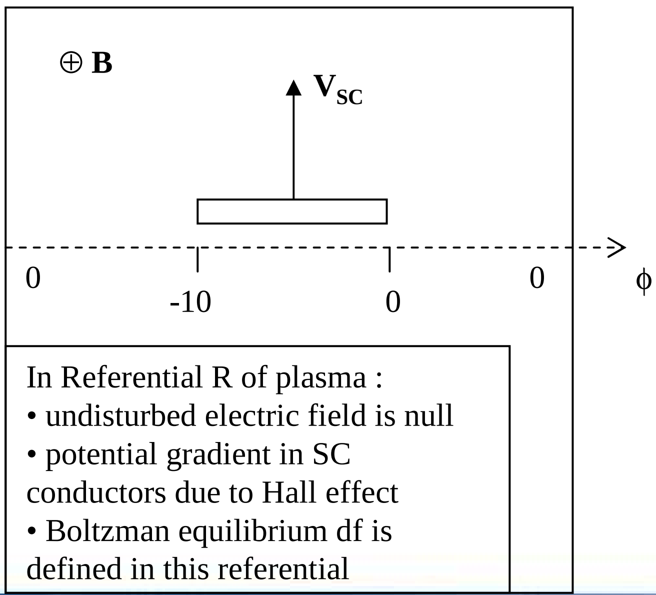


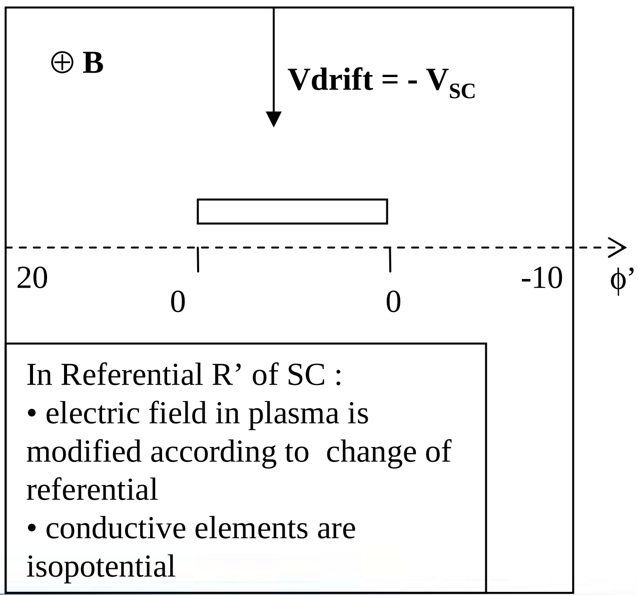
V cross B field

- Magnetically induced electric field
  - Spacecraft motion in a magnetic field → change of electric field $\mathbf{E'} = \mathbf{E} + \mathbf{V}_{SC} \otimes \mathbf{B}$
  - Chosen implementation : mix of the 2 referential frames
    - Poisson equation in R of plasma
      - BC on spacecraft due to Hall effect $\phi = \phi' + (\mathbf{V}_{SC} \otimes \mathbf{B}) \cdot x$
    - Particle dynamics in R' of spacecraft

$$\dot{x}' = v'$$

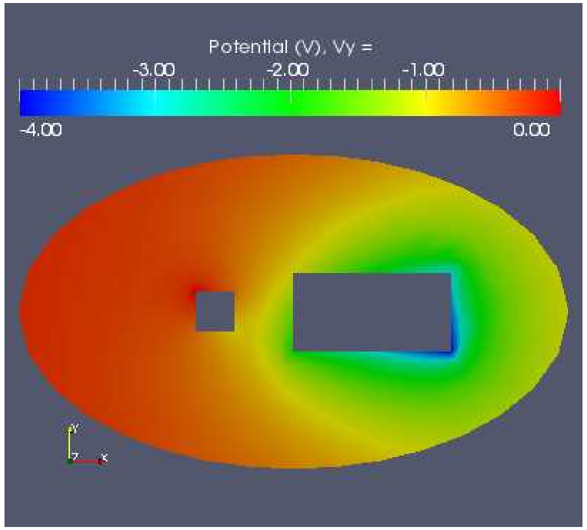
$$\dot{v}' = \frac{q}{m}\left(E + v' \otimes B + V_{SC} \otimes B\right)$$





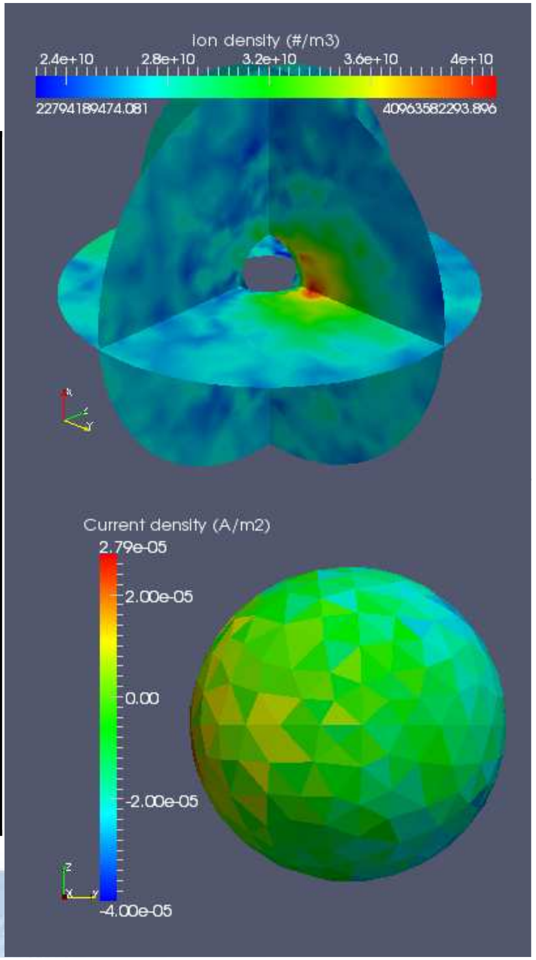
V cross B field

- Illustrative example
  - Spacecraft in LEO
  - B~5e-5 T, V ~7500 m/s, L~10 m
  - Potential drop of ~4V



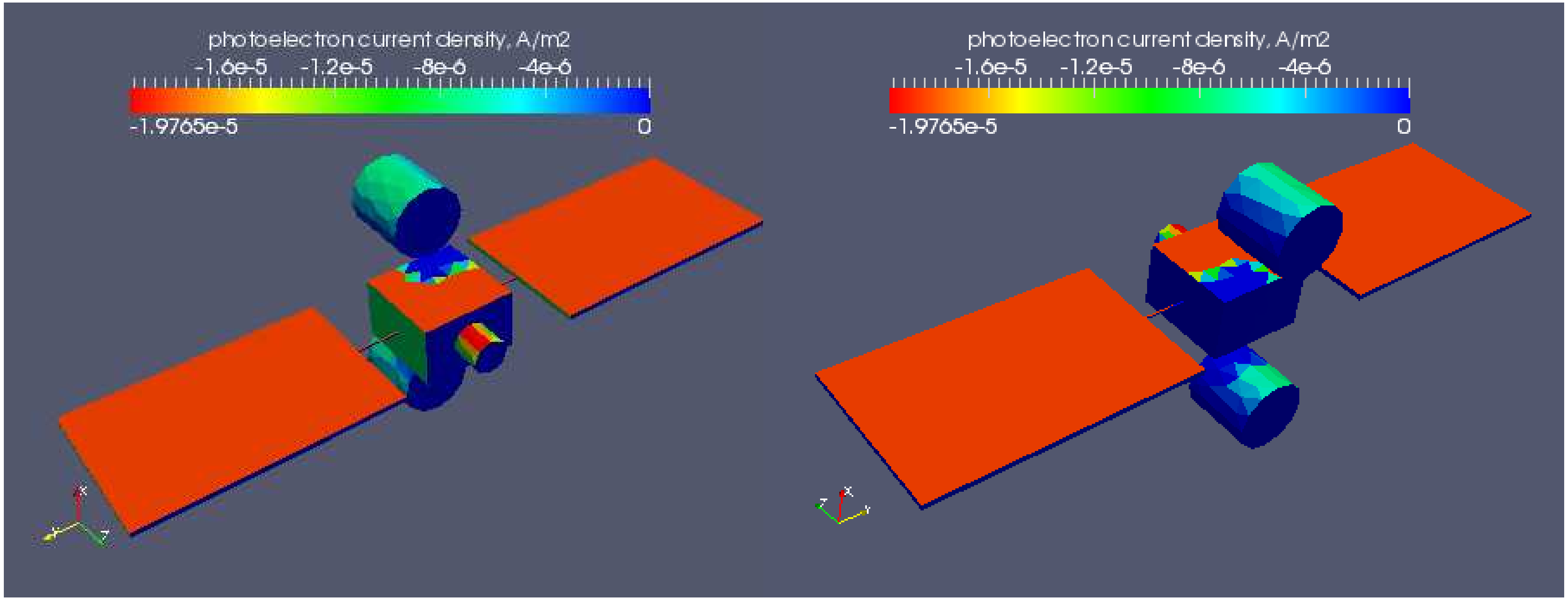
- Verification case
  - Correctly fits PTetra code: Marchand, IEEE Trans. Plasma Sci. 2012 (solved in R' of SC)

Quantity	Value
Temperature	0.2 eV
Electron/ion density	$2{,}8\times10^{10}$ #/m3
Debye length	0.02 m
Sphere radius R	0.02 m
Number of tetrahedrons	~40,000
Simulation box diameter	0.20 m
Number of macro-particles	~500,000
Bz	3×10^{-4} T
Electron Gyro Radius / R	0.18
Ion Gyro Radius / R	7.6
Spacecraft velocity Vy	- 7500 m/s
Floating potential	~ - 0.4 V



Self-shading

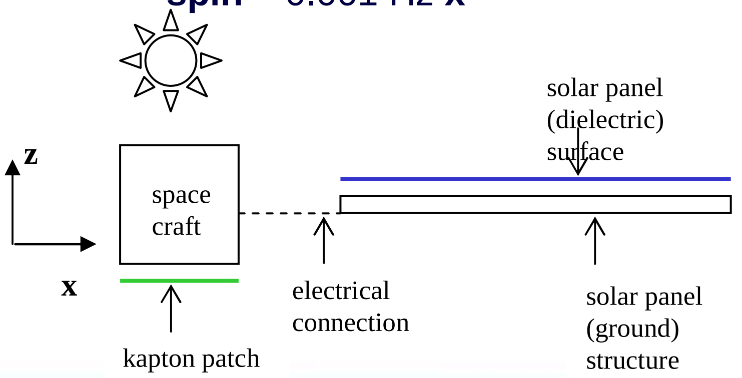
- In conjunction with SPIS-GEO

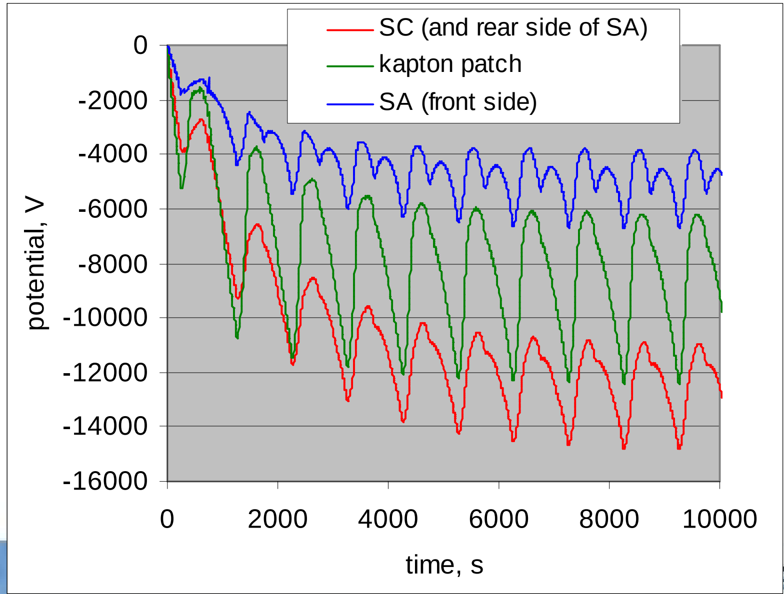


Transitions

- As of today: simulation with constant parameters
- New SPIS capability : Transitions
  - Parameters modified within the course of the simulation
  - User defined transition from
    - Global parameters for generic inputs (e.g. number, type of transitions)
    - ASCII files for dedicated inputs (e.g. sun flux change for an exit from eclipse)

- Spinning spacecraft
  - Change of sun flux (implemented) and plasma injection (not impl. yet)
  - Inputs: spin axis and angular velocity
  - Academic example of a spacecraft in GEO
    - **spin** = 0.001 Hz **x**

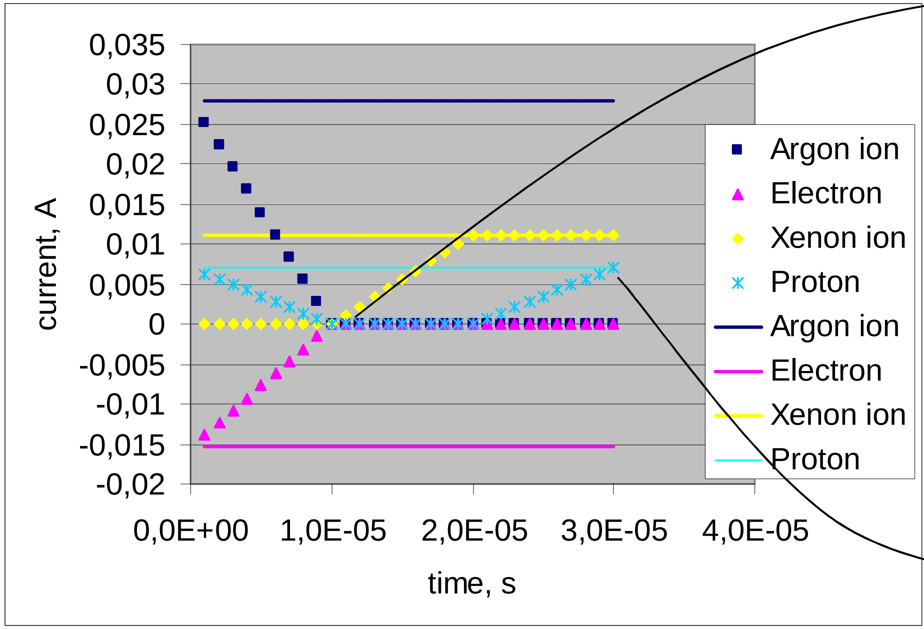


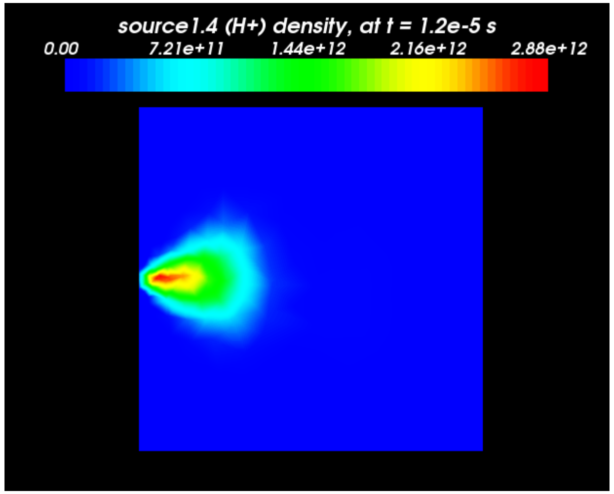


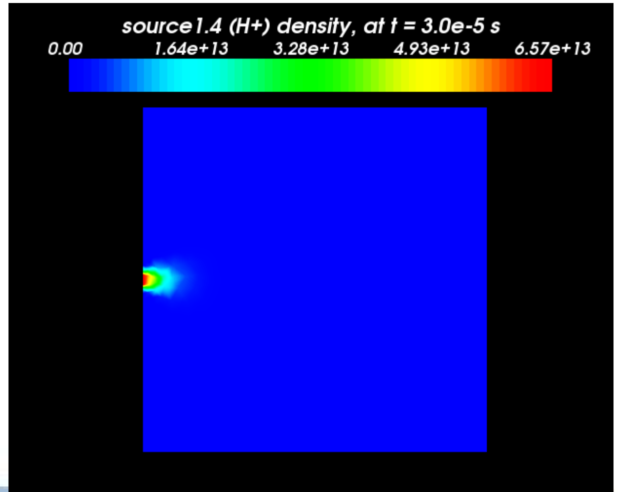
Transitions

- Eclipse exit
  - see SPIS-GEO presentation

- Plasma source activation







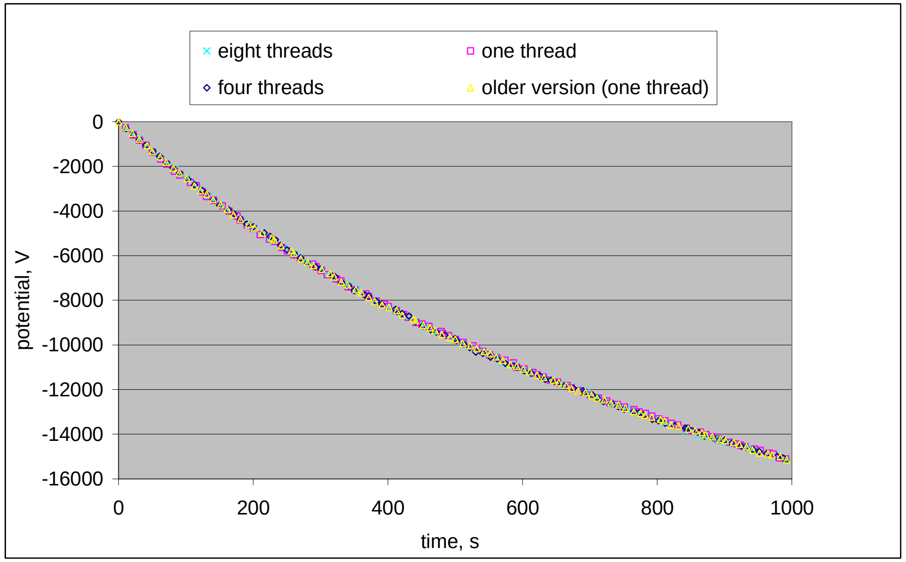
Monitoring CPU time

- Information on computational cost of SPIS numerical solvers
  - During the simulation
  - Summary at the end:

```
|-- End of SPIS numerical simulation --|
|-- Task durations
      |-- Task Simulation integration     | Cumulative duration :       25 MINUTES
      |-- Task Plasma    | Cumulative duration :       24 MINUTES
      |-- Task Plasma/SC Interactions     | Cumulative duration :       5 SECONDS
      |-- Task SC Circuit     | Cumulative duration :       46 SECONDS
      |-- Task Results storing      | Cumulative duration :       4 SECONDS
|--
|---- Plasma subtasks
      |-- Task Poisson Solver       | Cumulative duration :       131 SECONDS
      |-- Task Move all populations       | Cumulative duration :       22 MINUTES
       | At population level------
      |-- Task Injection of ions1 density component    | Cumulative duration :       9 SECONDS
      |-- Task Push of ions1 density component  | Cumulative duration :       5 MINUTES
      |-- Task Move of ions1 density component  | Cumulative duration :       5 MINUTES
      |-- Task Injection of ions1 current component    | Cumulative duration :       10 SECONDS
      |-- Task Push of ions1 current component  | Cumulative duration :       120 SECONDS
      |-- Task Move of ions1 current component  | Cumulative duration :       131 SECONDS
      |-- Task Injection of ions2 density component    | Cumulative duration :       11 SECONDS
      |-- Task Push of ions2 density component  | Cumulative duration :       228 SECONDS
      |-- Task Move of ions2 density component  | Cumulative duration :       248 SECONDS
      |-- Task Injection of ions2 current component    | Cumulative duration :       10 SECONDS
      |-- Task Push of ions2 current component  | Cumulative duration :       100 SECONDS
      |-- Task Move of ions2 current component  | Cumulative duration :       110 SECONDS
      |-- Task Injection of photoElec     | Cumulative duration :       44 SECONDS
      |-- Task Push of photoElec    | Cumulative duration :       210 SECONDS
      |-- Task Move of photoElec    | Cumulative duration :       261 SECONDS
      |-- Task Injection of secondElec     | Cumulative duration :       40 SECONDS
      |-- Task Push of secondElec    | Cumulative duration :       223 SECONDS
      |-- Task Move of secondElec    | Cumulative duration :       268 SECONDS
|--------------------------
```

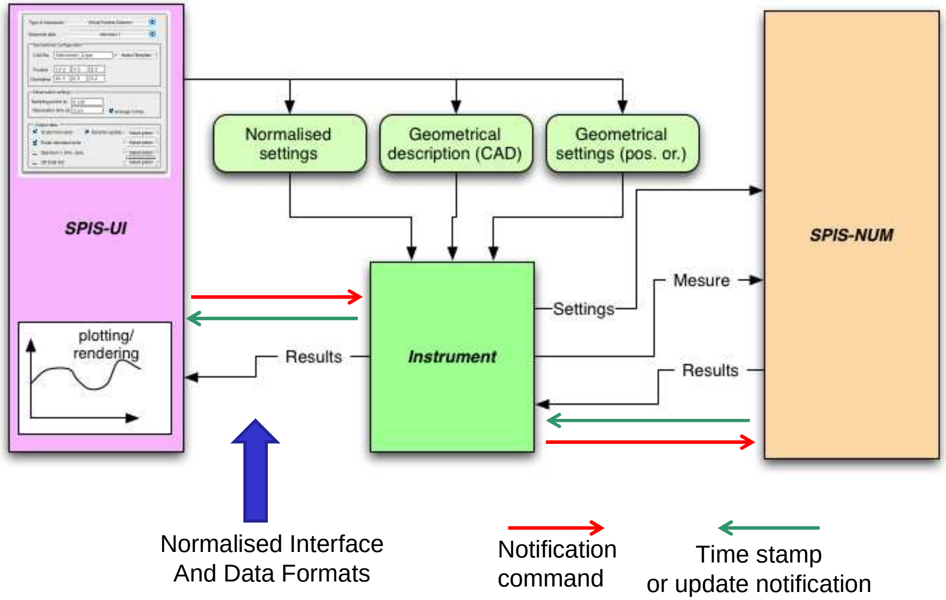
Multi-threading "parallelisation"

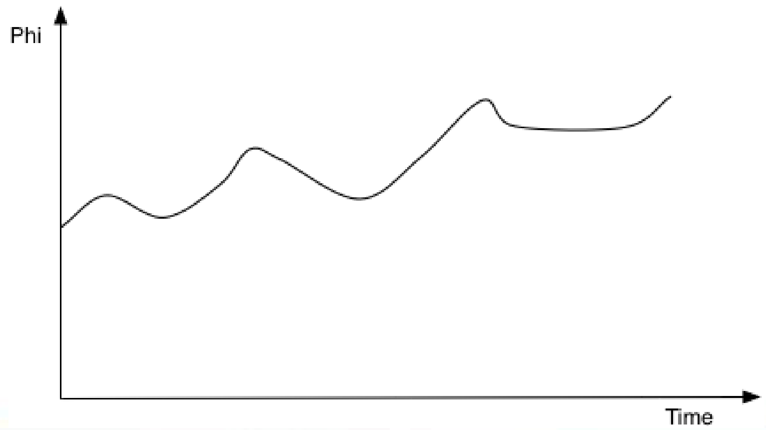
- The particle pusher is often the main CPU time consuming calculation
- Multi-threading approach
  - Based on Java Thread class
  - Good scale (ThreadNb vs. CPU time) when the particle pusher is very costly (lots of particle and large integration times)
  - Permit to reduce the cost of particle pushing to the same level as Poisson equation

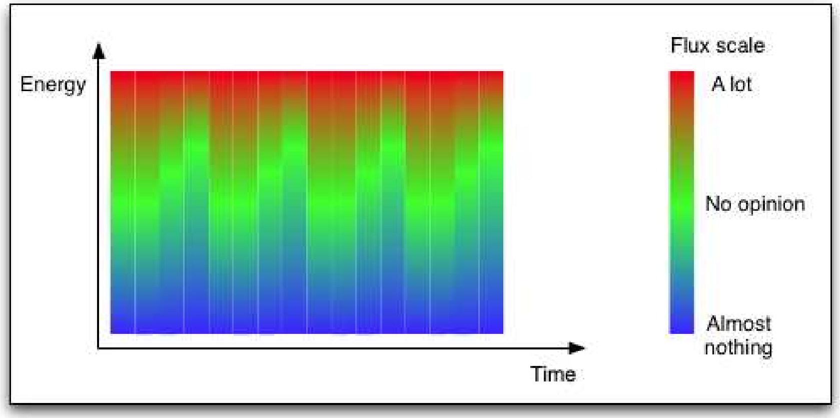


Scientific Instruments Design

- Plasma Sensors and Particle Detectors
  - Location
    - On single point of the plasma volume
    - On an instrument (possibly virtual)
  - Temporal measurement
    - Regular observations
    - On user demand (interactive mode)
  - Outputs
    - Distribution functions and first momentum
    - Plasma potential







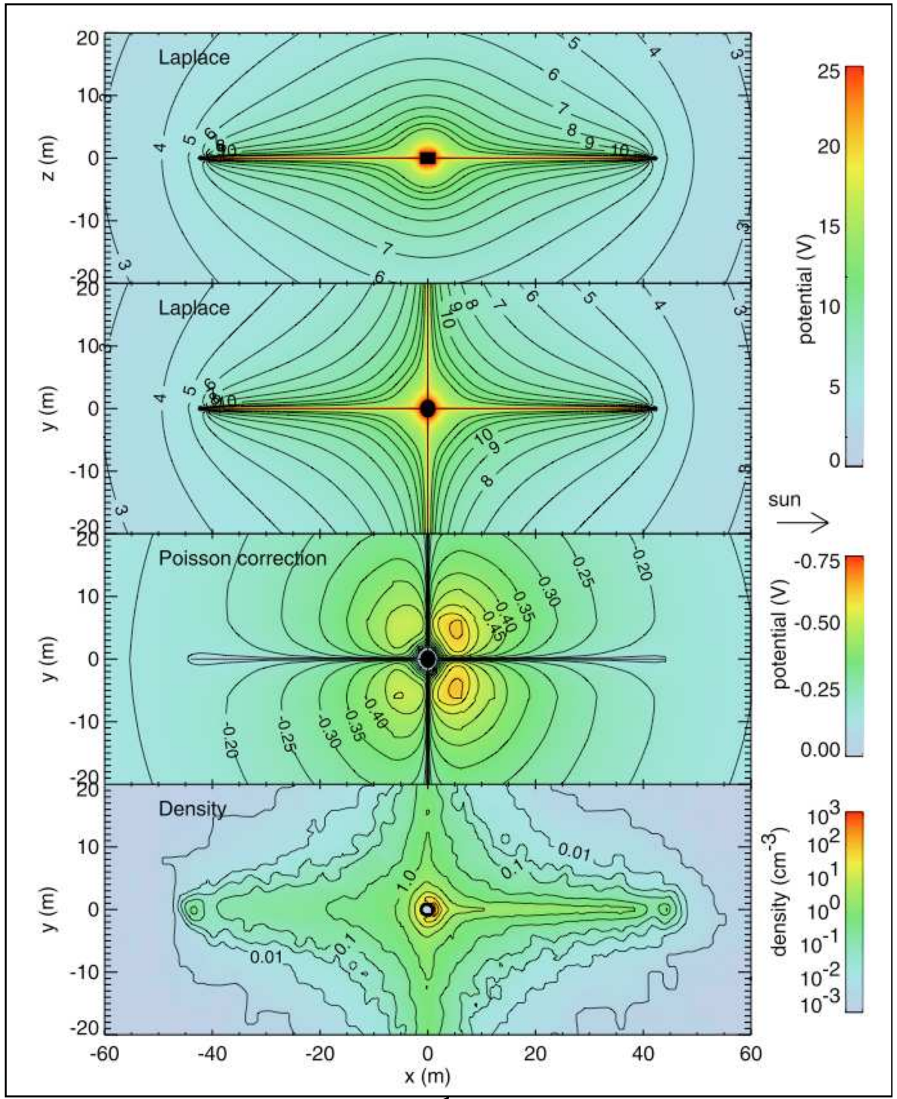
Scientific missions modeling – Validation cases

- 5 validation cases / 3 missions have been defined
  - Currently under development by specialists of electric field sensor and particle detectors involved in several scientific missions : IRF (Sw) and IRAP (F)

Case	1	2	3	4	5
Scope	Cluster E-field measurements	Cluster electron measurements	Solar Orbiter E-field measurements and wake	Solar Orbiter electron measurements	Cassini electron measurements
S/c relevance	Bepi MMO MMS	Bepi MMO MMS	Rosetta JGO SP+ Demeter	SolO Bepi MPO Rosetta SP+	JGO Rosetta
Plasma conditions relevance	Bepi MMO MMS	Bepi MMO MMS	Bepi MMO Bepi MPO SP+	Bepi MMO Bepi MPO SP+	JGO Rosetta Demeter
Relevant existing databases	Cluster	Cluster	Rosetta	Rosetta Helios Stereo	Cassini
Relevant previous studies	[Cully2007] [Mihljcic2010] [Miyake2011] [Thiébault2003] [Thiébault2004]	[Mihaljcic2010] [Pedersen2008] [Szita2001] [Thiébault2003] [Thiébault2004]	[Engwall2006]	[Ergun2010] [Isensee1981] [Katz2001] [Sjögren2009]	[Jacobsen2009] [Laframboise1974] [Lewis2010] [Nilsson2009] [Olson2010]

Validation Case 1 - Cluster E-field

- Cluster attractive features
  - Complete set of high-sensitivity plasma instruments onboard
  - Large and accessible database
  - Several studies on s/c-plasma interaction
  - High interest from the scientific community
  - Relevance for Bepi-Colombo MMO, MMS, Themis …
- Model
  - Spacecraft, wire booms, spherical probes and adjacent electrical elements
  - From 0.3 mm thickness to 88 m probe-to-probe distance
  - Currents to small bodies crucially depends on test particle tracking
- Comparison
  - Other codes (Miyake2011, Cully-2007)
  - In-orbit study (Mihaljcic2010,)



Validation Case 2 - Cluster electron measurement

- Different conditions
  - Tenuous Solar wind at Earth orbit
  - Dense Solar wind at Earth orbit
  - Polar cap

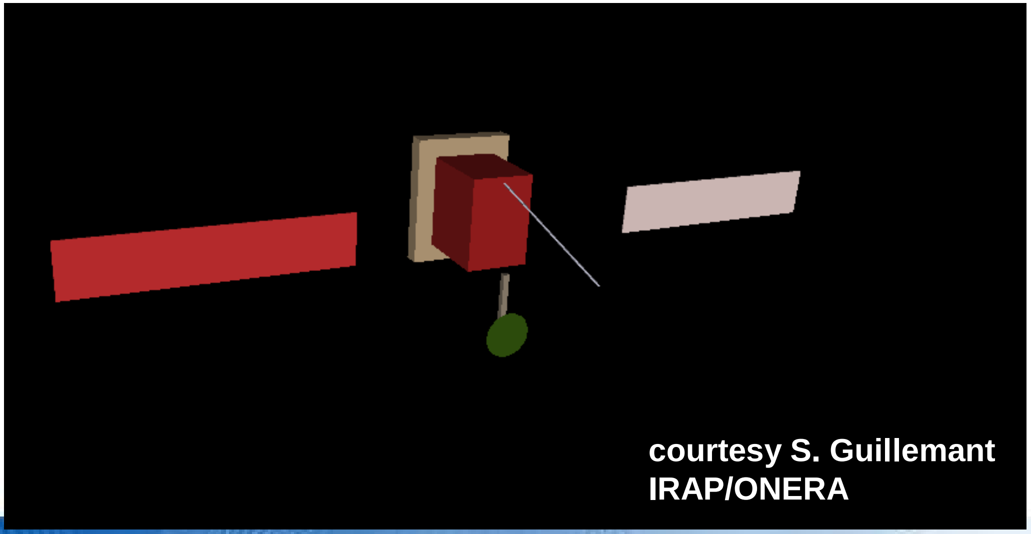
- Model
  - Electron detectors

- Objectives
  - Quantification of photoemission and secondary emission

- Comparison
  - measurement with PEACE

Validation Case 3 - Solar Orbiter electron measurements

- Objectives
  - Electron instrument (located on an anti-sunward boom)
  - Potential barrier can form around the spacecraft out of combined effects of photoelectron emission and ambient electron density
  - Quantification of the photoemission and of the secondary emission
  - Effect of ≠ Distribution functions: Maxwellian, Kappa or user defined from observations
- Comparison
  - SPP simulations [Ergun2011]
  - Distribution functions obtained by a simulated electron instrument (SWA/EAS).

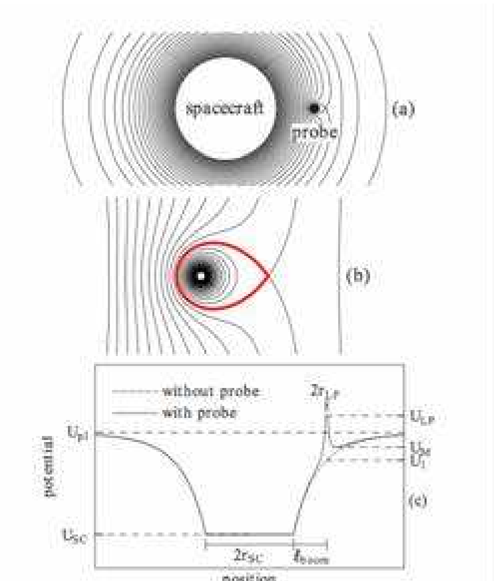


Validation Case 4 - Solar Orbiter E-field and wake

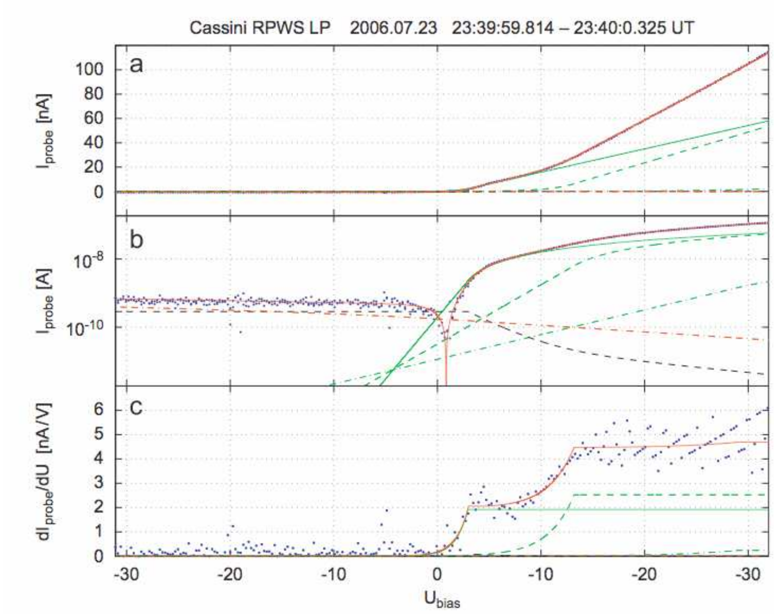
- Objectives
  - Wake effect on the electron instrument
  - Electric potential pattern near the antennas
  - Possibly several solar panel orientations
  - Effect of non-conducting solar panels on electric field measurements

Validation Case 5 - Cassini

- Objectives
  - Current-voltage characteristics of the Langmuir probe



Olson2010



Validation Case 5 - Cassini

- Other objectives still to be defined in detail
  - Influence of photoelectrons and spacecraft potential on electron measurements of RPWS-LP and ELS @ negative and positive spacecraft potential
  - Effect of secondary electron emission on the RPWS-LP bias voltage sweeps
    - Some sweeps [Garnier2011] show a region of negative resistance
    - Direct effect of secondary emission
  - Or Bfield effect and wake effect

- Model
  - Particle detectors and Langmuir Probes

- Comparison
  - A good set of high-sensitivity plasma instruments onboard
  - Large and accessible database, several studies on SC interaction and measurement [Jacobsen2009, Nilsson2009, Olson2010, Lewis2011]

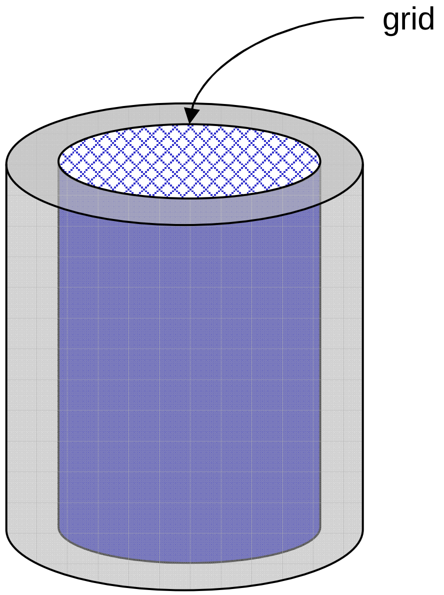
Summary

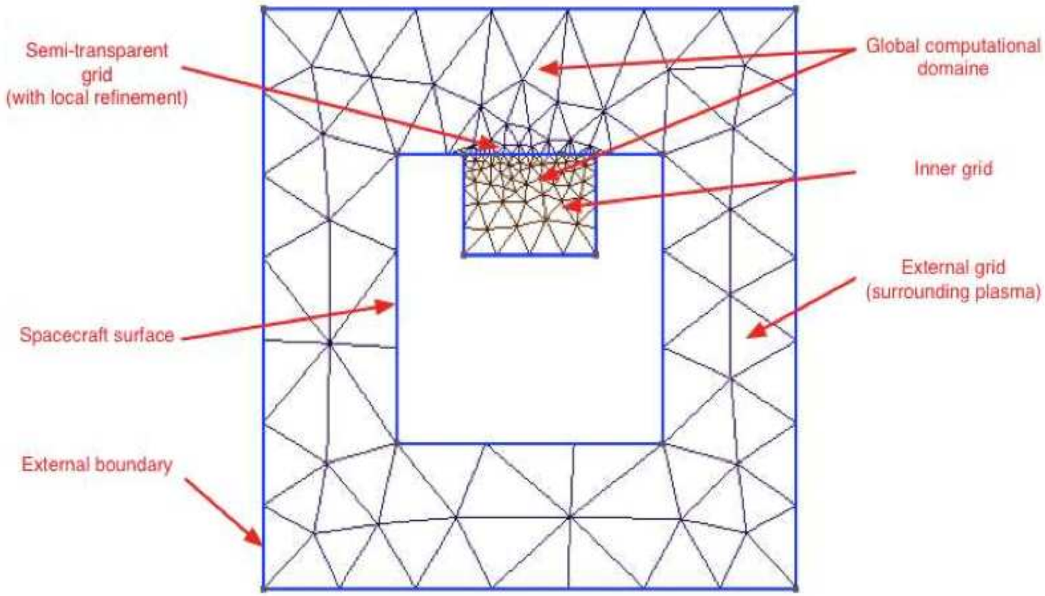
- Thanks SPINE community for providing ideas of SPIS development and validation cases !
- See you at 12th SCTC and next SPINE WS !

Reserves

Semi-Transparent Grids

- Useful to model some specific instruments
- Work performed
  - Definition of the STG format: mesh, dependencies of the circuit solver, particle pusher





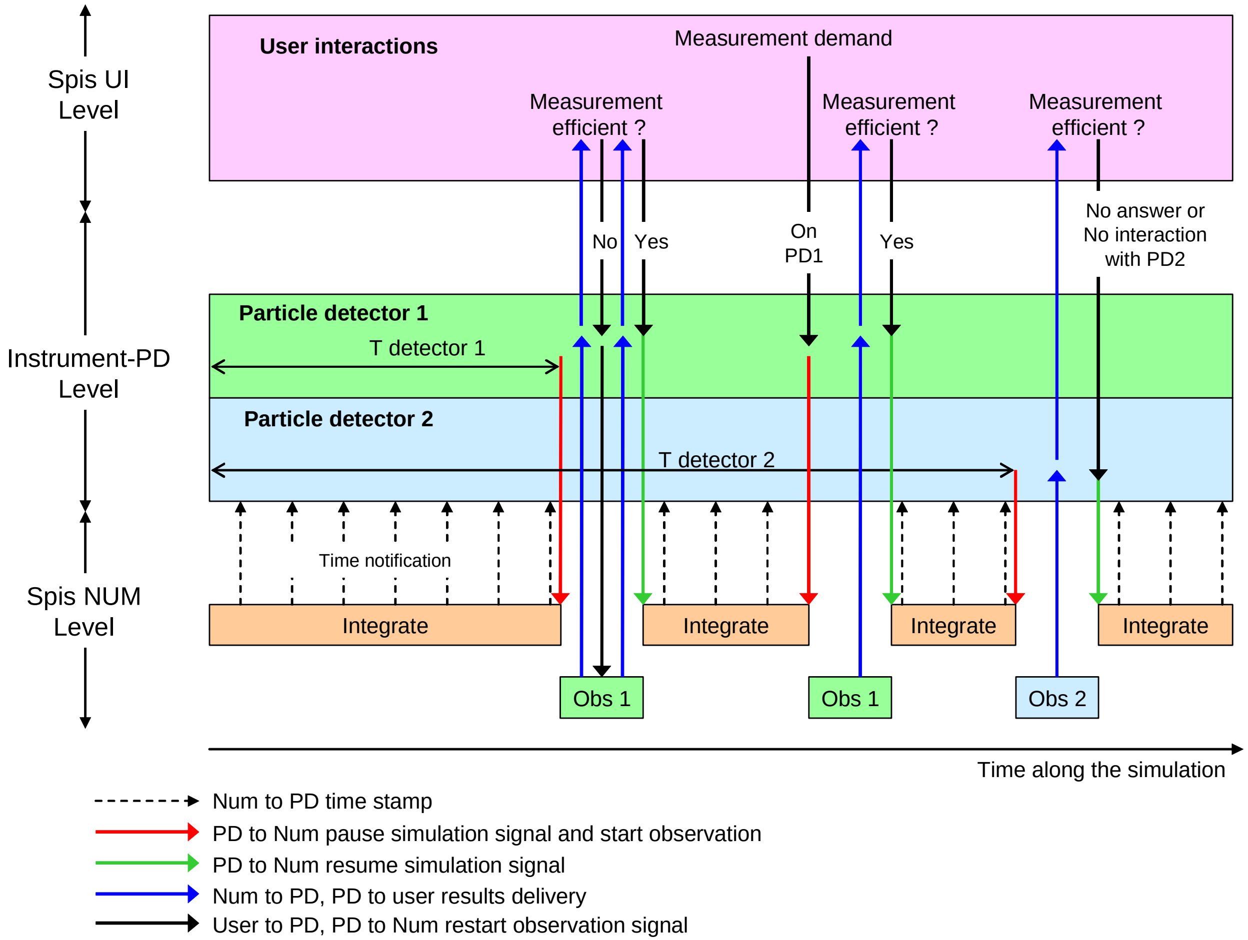
Particle Detectors Design

Key aspects
- provide good statistics results on small instruments compared to SC

Test Particle (TP) method
- “Frozen” simulation
- Mix of Forward tracking and Backtracking of TP populations
- Increase statistics on instruments surfaces

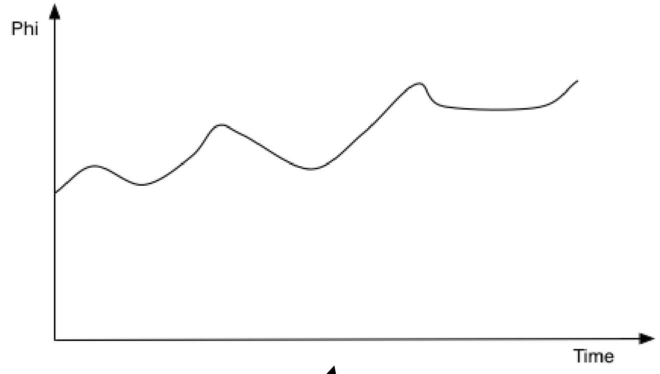
Settings
- Pre-defined parameters
- Interaction with the user
  - modify energy range
  - super-particle number

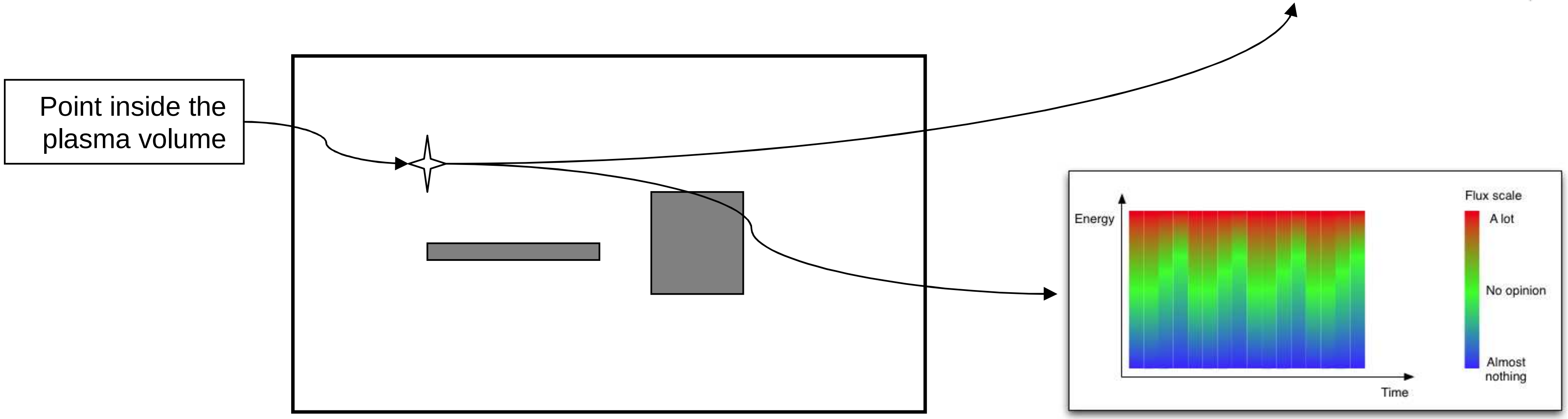
Work progress
- Design of new package
- UI / Instruments / NUM package interfacing



Plasma Sensors progress

- Provide light data concerning the simulation
  - Plasma potential
  - Energy distribution function and density
  - At a single point of the simulation
  - Using the PIC populations of the simulation (no TP)





- Useful to check the convergence of the simulation
- Work performed so far
  - Numerical routines OK
  - User Interface wizards : still to be implemented