SPIS-MAINTENANCE

SPINE Meeting **ESTEC, Noordwijk, NL, 19th of March 2013**

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ARTENUM, PARIS
Science & Groupware (2)

ONERA (1)
THE FRENCH AEROSPACE LAB

return on innovation

Context

- CCN 1 to ESA/ESTEC contract 4000102091/10/NL/AS
  - Technical Officer: David Rodgers
  - Partners: ONERA, ARTENUM

- SPIS software is used by an increasing community with increasing needs
  - Training
  - Debugging
  - Extensive validation assessment
  - Verifying their own developments have no unexpected side-effects

- Objectives of this activity
  - Correct bugs reported by ESA
  - Organize a training course at ESTEC : more than 20 people trained last year
  - Develop a non-regression procedure → this presentation

Non-regression procedure

- Objectives
  - Test parts of the code.
  - Help the developers to verify the non-regression of their contribution.
  - Extend the number of simulation cases achieved by SPIS and provide them to the community

- Comparison with theory or other codes
  - Using Spis 4.3.2
  - Delivery of new cases
  - Update of existing cases

- Outputs
  - Achieved : Technical sheets supplied to European Spatial Agency (ESA) and all the interested developers
  - Under progress: automatic procedure to run cases and check non-regression (spis 5)

➢ Studied case: Current collection by a metallic sphere (radius R_p) at a positive potential (Φ) for long and short Debye length(λ_D).

- Collection of repelled (ions) and attracted species (electrons) [4], [5]:
  - Ion collected current (density n_i, temperature T_i, masse m_i):

$I_i = I_i(0) exp\left(-\frac{e\phi}{kT_i}\right)$ shift by a factor $exp\left(-\frac{e\phi}{kT_i}\right)$.

  - Electron collected current (density n_e, temperature T_e, masse m

Several theories were published: OML theory in 1926 ($R_p/\lambda_D < 5$).

$$I_e = I_e(0)\left(1 + \frac{e\phi}{kT_e}\right)$$

Laframboise's theory stays the reference.
In 1963 he extends the OML theory to broad R_p/λ_D ratios.

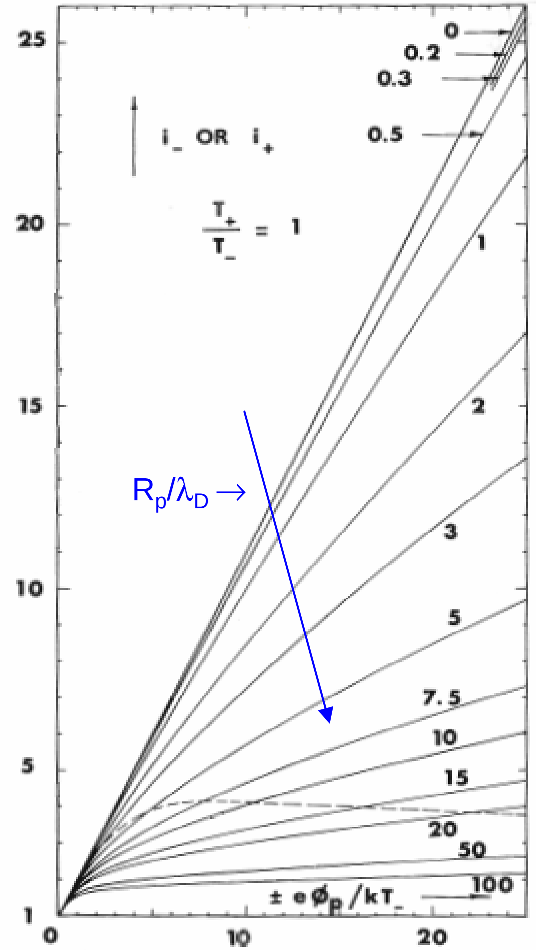
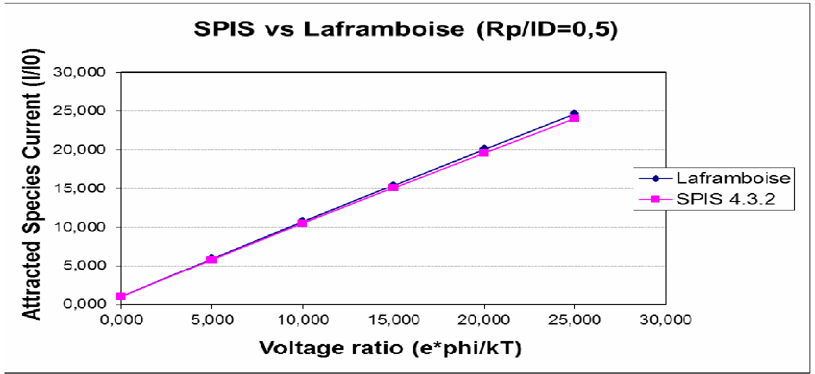
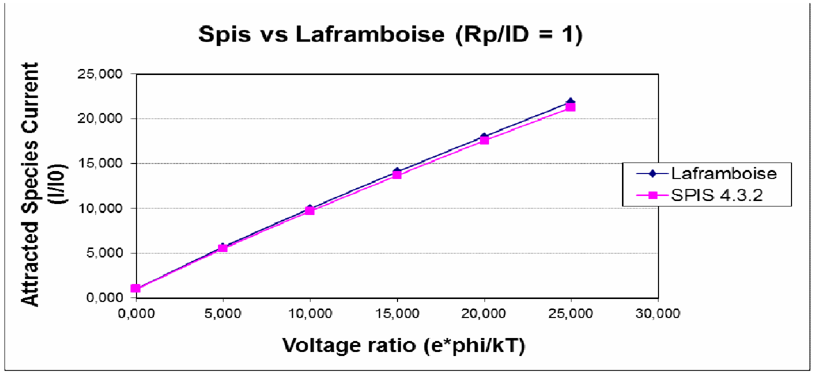


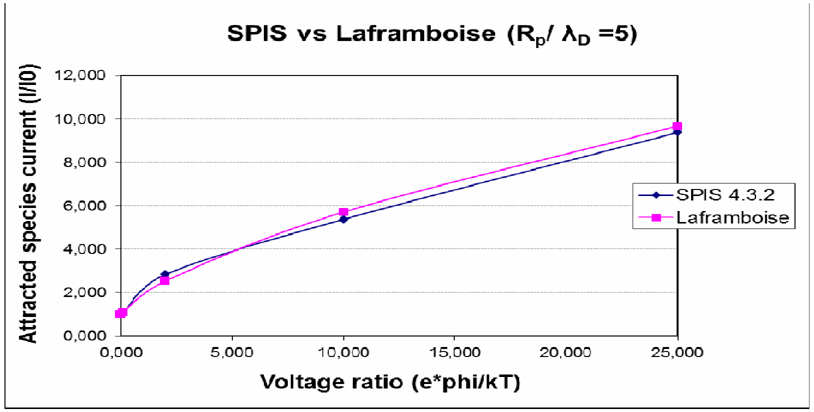
Figure extracted from Theory of spherical and cylindrical Lan probes in a collisionless Maxwellian plasma at rest. [7]

Spherical probe

- Potential sweep scenario (0 to +25*kTe/e) for three probe ratios (Rp/ λD = 0,5 top left-hand corner, 1 top right-hand corner and 5 bottom center).

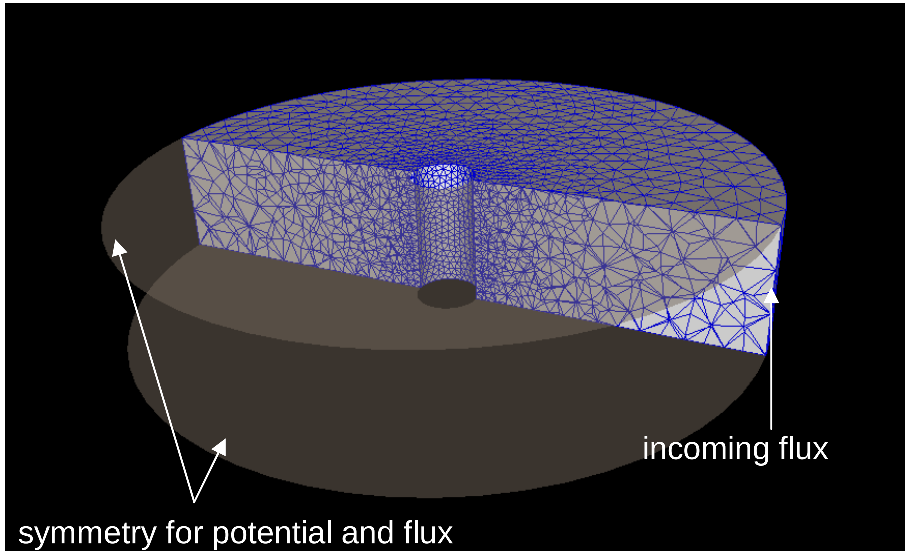




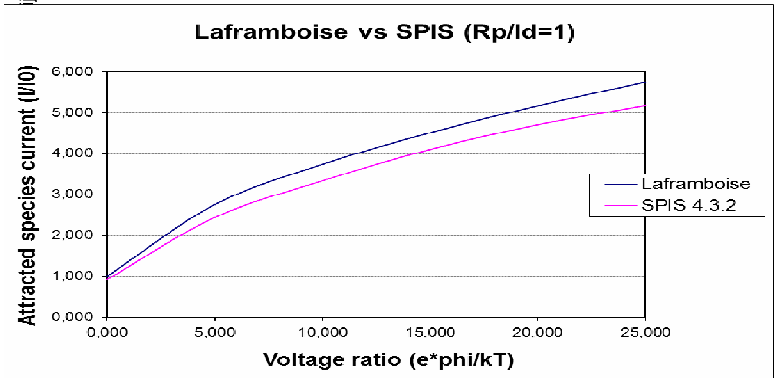


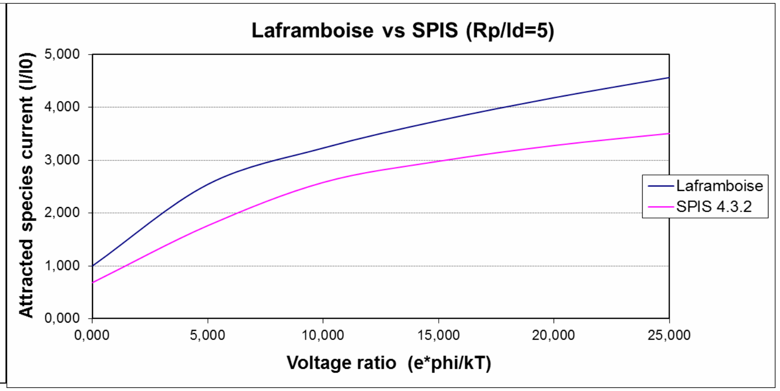
- Results close to Laframboise (error < 3%) for high Debye lengths, some difficulties for small Debye lengths
- Even better with SPIS 5 (see tomorrow presentation)

Quasi-infinite cylinder probe



- Simulation launched for $R_p/\lambda_D = 1$ and $R_p/\lambda_D = 5$.
- Error around 10 %
- but < 1% with next SPIS version.





Floating non-emitting sphere

- Studied case: Determination of floating potential for a sphere immersed in plasma.

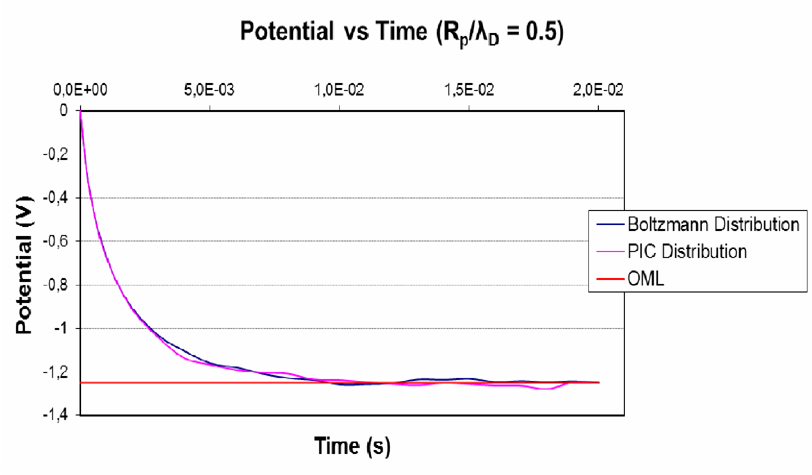
  - OML theory: $I_e = I_e(0)\left(1 + \frac{e\phi}{kT_e}\right)$ (1)
    $I_i = I_i(0)exp\left(-\frac{e\phi}{kT_e}\right)$ (2)

    (1) = (2) => Spitzer gives the following value for H^+ ions: $\emptyset = -2.5kT_e$ [5]

- SPIS results / OML theory comparison:

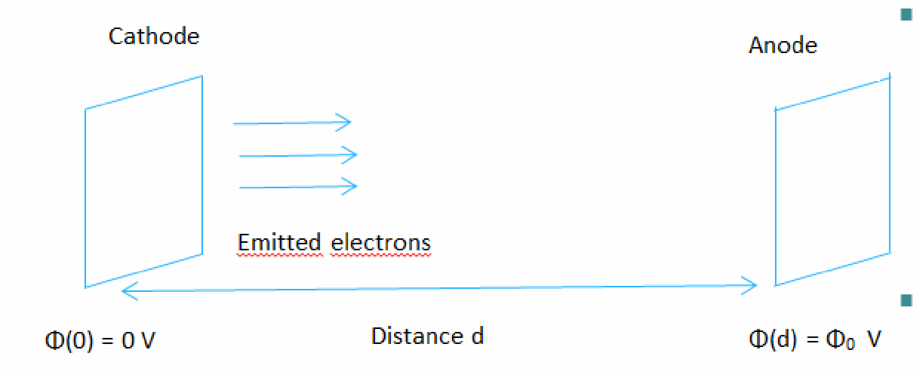
  - Two cases with large Debye length to apply OML theory.
  - Two distributions used: Full PIC distribution (PIC ion – PIC electron) and Hybrid distribution (PIC ion – Boltzmann electron).

Probe ratio	Floating potential - Full PIC (V)	Floating potential - Hybrid distribution (V)	Floating potential - OML (V)
$R_p/\lambda_D = 0.5$	-1.261	-1.246	-1.25
$R_p/\lambda_D = 1$	-0.509	-0.504	-0.5



Emission limited by space charge

- Mono dimensional Child-Langmuir configuration

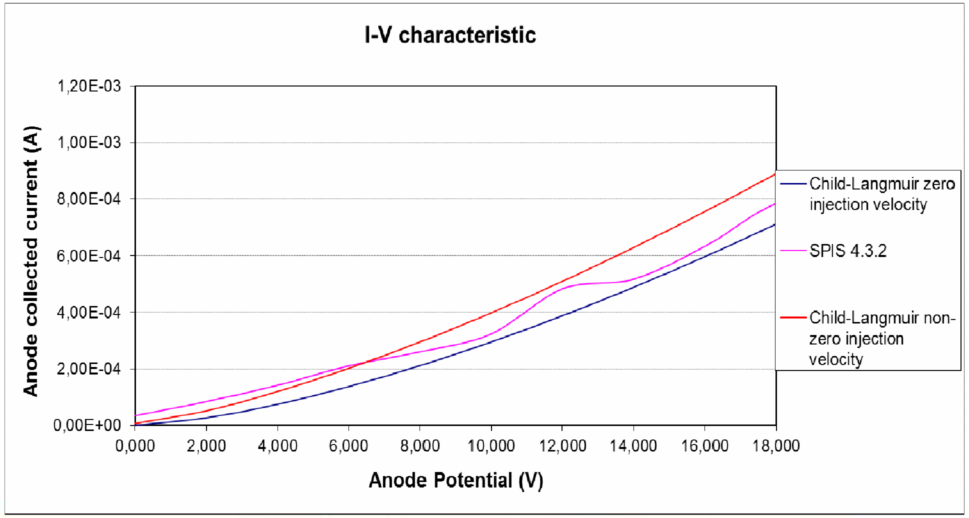


- Child-Langmuir's law obtained from Poisson's equation, Energy and flux conservation:

$$J_e = J_{CL} = -\frac{4}{9}\left(\frac{2e}{m_e}\right)^{1/2}\frac{\varepsilon_0 \phi_0^{3/2}}{d^2}$$

- With a non-zero injection velocity v_0 [8]:

$$J = J_{CL}\left[\left(\frac{m_e v_0^2}{2e\phi_0}\right)^{\frac{1}{2}} + \left(1 + \frac{m_e v_0^2}{2e\phi_0}\right)^{\frac{1}{2}}\right]^3$$



Distance d = 1 cm
Source temperature kT_e = 0,2 eV
Potential ranging from 20 V ($100kT_e$) to 0
Source current density = J_e max

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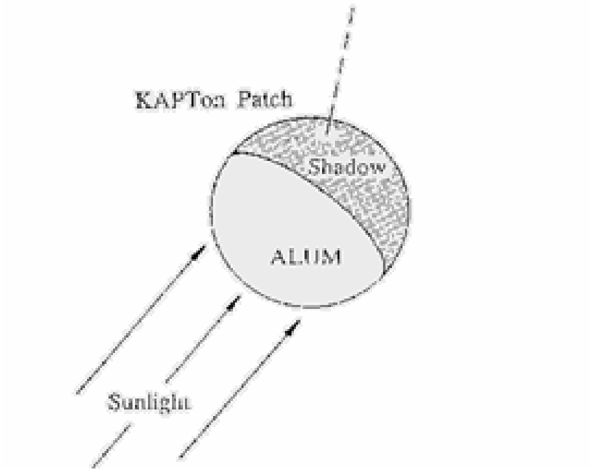
Small patch charging on a spherical body

- Comparison with EQUIPOT



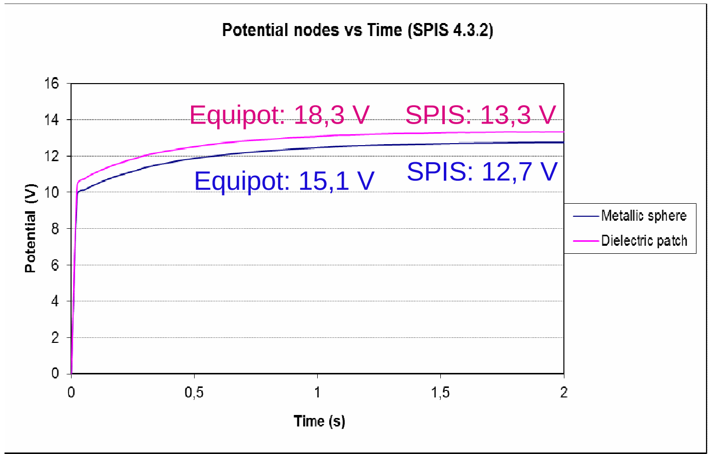
- Equipot is a code accessible via html and implemented in SPENVIS
- User has access to:
  - the environment choice
  - the material properties
  - the spacecraft illumination
- Supplied results concern
  - The steady-state potentials
  - The steady-state currents

Small patch charging on a spherical body

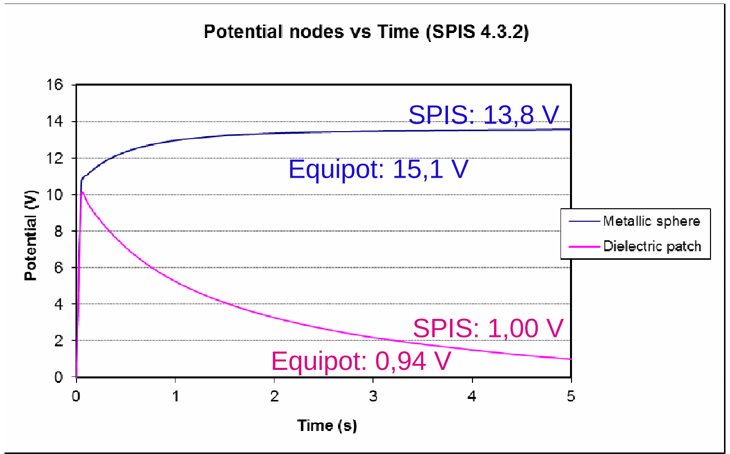
Aluminum sphere and kapton patch in quiet GEO enviornment

		Sunlit patch			Shadowed patch		
Observables	**Part of S/C**	**SPIS 4.3.2**	**Equipot**	**Differences / Comments**	**SPIS 4.3.2**	**Equipot**	**Differences / Comments**
Net Photoelectron current density (A/m²)	**Metallic sphere**	7.96 E-07	7.94 E-07	0.3 %	8.38 E-07	8.07 E-07	3.8 %
	Dielectric patch	7.55 E-07	9.47E -07	20.2 %	-8.99 E-08	1.05E -21	ok
Net SEE current density (A/m²)	**Metallic sphere**	4.31 E-07	4.37 E-07	1.4 %	4.11 E-07	4.38 E-07	6.3 %
	Dielectric patch	3.39 E-07	3.09 E-07	9.6 %	1.17 E-06	1.24 E-06	5.9 %

Sunlit patch



Shadowed patch



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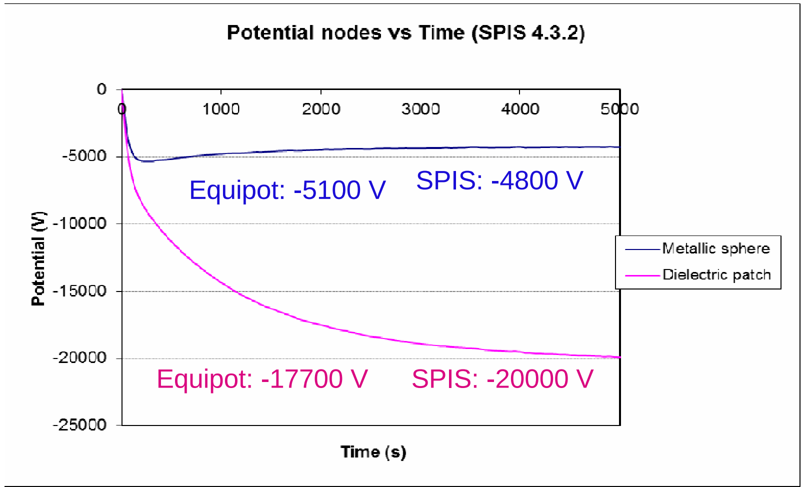
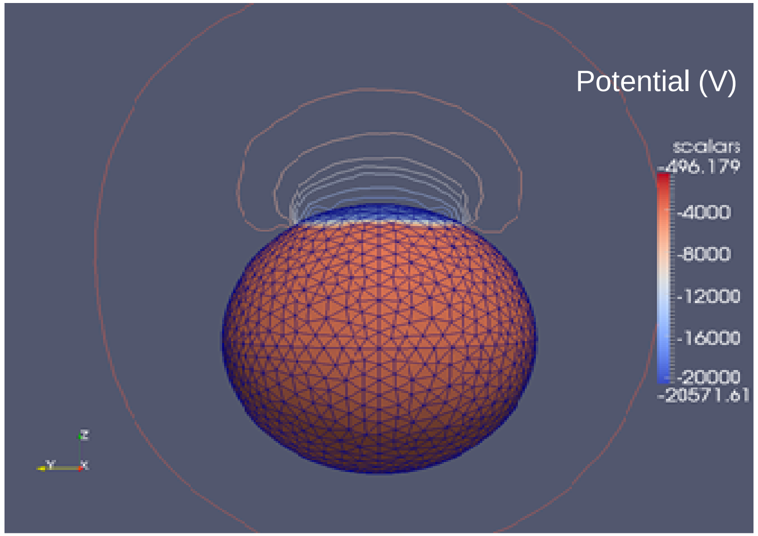
Small patch charging on a spherical body

Gold/Teflon configuration in shadow and charging environment

Observables	Part of S/C	SPIS 4.3.2	Equipot	Differences / Comments
Net SEE current density (A/m^2) (collected – emitted)	Metallic sphere	5.60 E-06	5.31 E-06	5.5 %
	Dielectric patch	1.56 E-06	1.58 E-06	0.9 %
Net total current density (A/m^2)	Metallic sphere	2.69 E-09	-5.00 E-09	$J_{net} = 0$
	Metallic sphere	5.60 E-06	5.31 E-06	5.5 %





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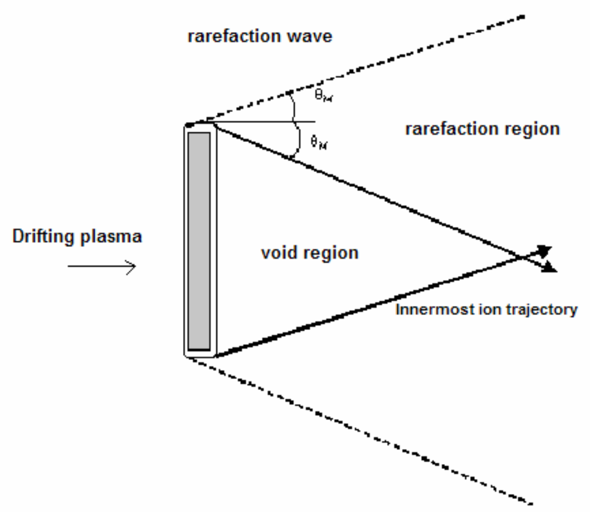
Plasma wake

➢ Studied case: Spacecraft to a null potential immersed in a drifting plasma.

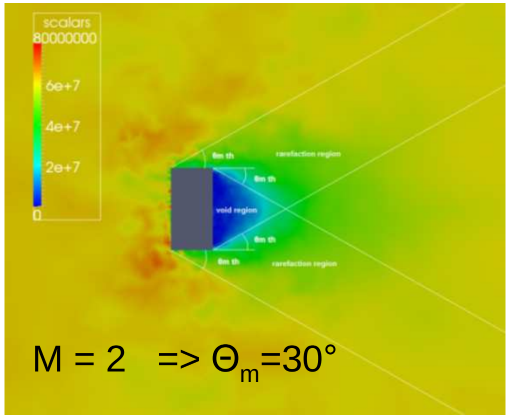
- Wake structure scheme:

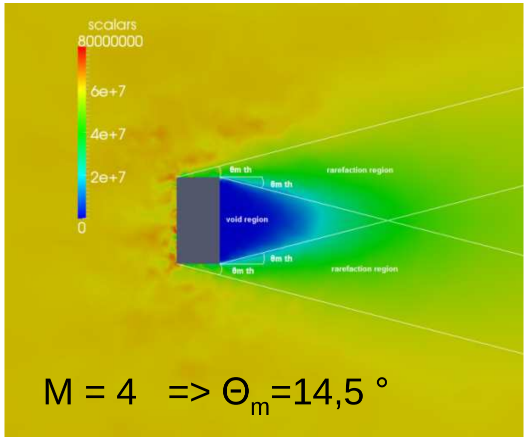


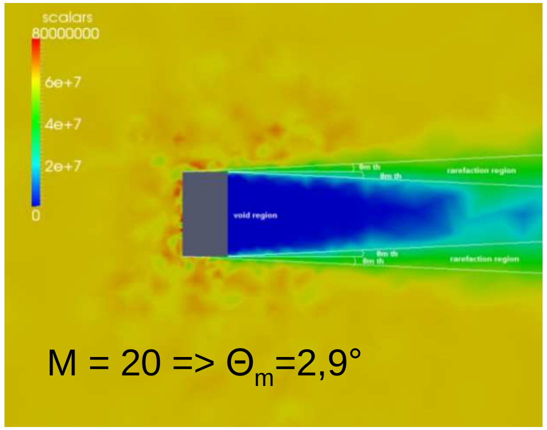
- Interaction between the stationnary spacecraft and the drifting plasma.
- In front of the plasma flow, ion collection improved.
- Downstream of satellite, void or rarefaction region for ions (not the required velocity) and for electrons (space charge creation).
- Θ_m is the Mach angle: $\theta_m = \arcsin\left(\frac{1}{M}\right)$
  M is the Mach number: $M = \frac{v_d}{v_i}$ with v_d the drift velocity and v_i the thermal ion velocity.

- Potential and current determination:
  - OML theory for the electron current collection and the ion current collection on the lateral surface.
  - $I_i = eN_iAv_d$ for the ion front face collected current (correct for a high Mach number).
  - Gauss theorem for the potential calculation.

Plasma wake - Ion density







- Void region
- Rarefaction region
- Plasma ion density

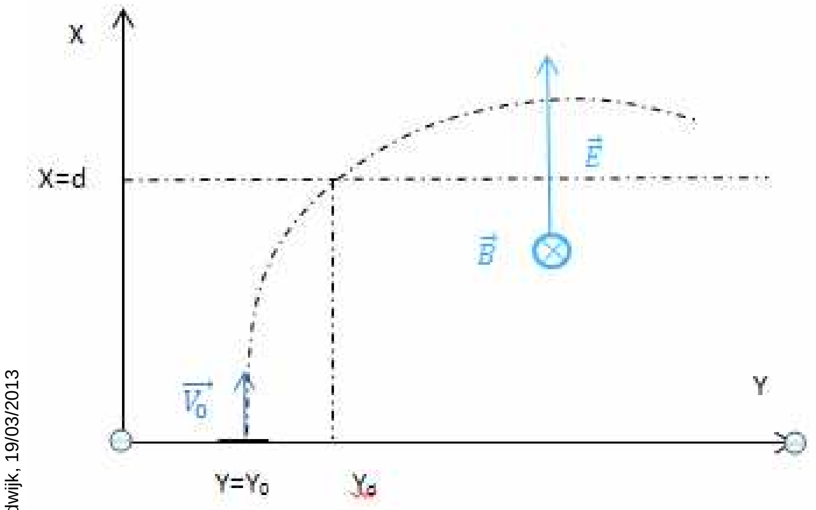
Error < 1 % on collected currents vs. theory

Potential in the wake close to theory (Gauss)

Particle motion in E cross B field

- Studied case: Describing the particle trajectory in E cross B field (constant and uniform fields).

- Analytical model:



Lorentz force: $\frac{d\vec{V}}{dt} = \frac{q}{m}[\vec{E} + \vec{v}\wedge\vec{B}]$

Integrations over time:

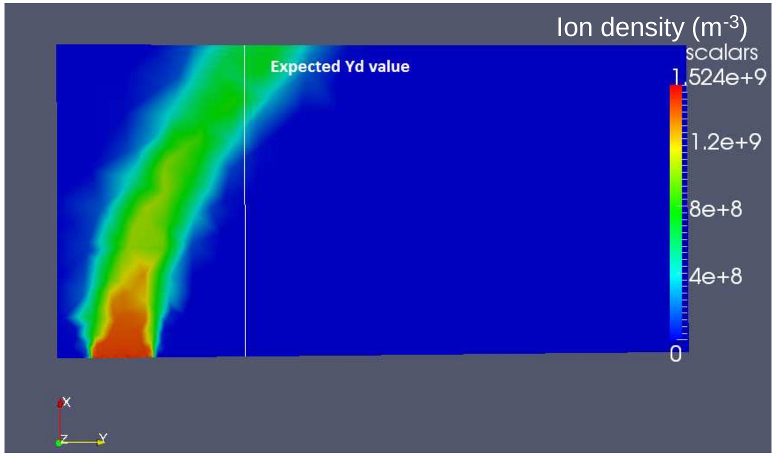
$$X(t) = \frac{V_0}{\omega_0}\sin(\omega_0 t) - \frac{E}{B\omega_0}\cos(\omega_0 t) + \frac{E}{B\omega_0}$$
$$Y(t) = \frac{E}{B\omega_0}\sin(\omega_0 t) + \frac{V_0}{\omega_0}\cos(\omega_0 t) - \frac{E}{B}t + Y_0 - \frac{V_0}{\omega_0}$$

With $\vec{V_0} = V_{0X}\vec{X}$ and $\omega_0 = \frac{qB}{m}$

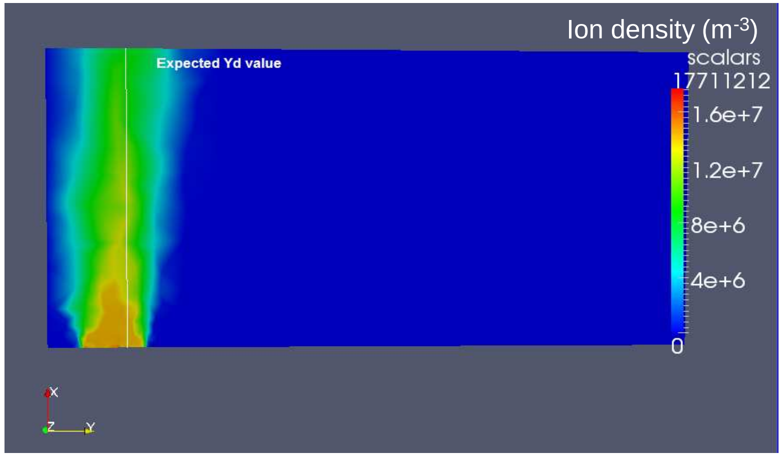
- Matlab results:
  - Y_d value for several electrode potentials and several ion temperatures.
  - Comparison with SPIS for two cases: - electrode potential = -10V
    - ion temperatures = 10 eV or 1000 eV

Particle motion in E cross B field

Case 1 (ion temperature = 10 eV)



Case 2 (ion temperature = 1000 eV)



A total of 17 cases

- 4 extra comparisons with EQUIPOT
- Sphere with thin wires
- GEO case

17 Technical Data Sheets attached to Spis4 projects

Ref : SPIS_NRC_SphereCharging_case1_TDS1 — version : 1.1
Author : JC Mateo-Vélez, B. Rivière — date : 28/08/2012

SPIS Non Regression Case - Technical Data Sheet 1

Test case name	Charging of non-emitting absorber in Maxwellian Plasma – Large Debye Length (Radius/Debye_length=0.5)		
Summary	Determination of the equilibrium potential of a spherical probe in large Debye length regime for two electron distributions (PIC and Boltzmann). Ions follow a PIC Distribution. Reference data from OML (Orbital Motion Limit) and Laframboise.		
Date of creation	19/04/2012		
Author :	JC Mateo-Vélez(ONERA/ DESP): mateo@onera.fr B. Rivière (ONERA/ DESP): benjamin.riviere@onera.fr		
Modification date	28/08/2012	Reasons of change	- Adding the number of super-particles in TDS2 - Adding all the time steps - Filling in the table for improvements/differences

Description

	Description
Geometry	Spherical probe radius : 0.1 m
Plasma	Maxwellian electron and protons: • $kT_e = kT_i = kT = 0.5$ eV • $N_e = N_i = N = 6.91\times10^6$ m^{-3} • Debye length = 0.2 m • Electron/ion thermal current density : $j_e = -1.31E-05$, $j_i = -3.05E-07$ A/m² • Plasma Frequency : 236 kHz
Spacecraft	Floating potential

Challenges/Observables

#	Description	Comparison to	Pass/Fail criteria
1	Potential on the probe	-Laframboise, 1966 -Orbital Motion Limit theory by Mott-Smith and Langmuir, 1926	< 3 % error

SPIS Model

	Description	Associated File
SPIS project	All Dataset	Simulation/ SPIS_NRC_SphereChargingLDB_case1.spis
Mesh	Spherical probe mesh refinement = 0.02 m Meshed surface on probe External box diameter: 1 m External box mesh refinement: 0.1 m Mesh size: 53995 tetrahedra	Simulation/ SPIS_NRC_SphereChargingLDB_case1.spis/ Geom/GEOM
Matter	Model 1: • Electron: PICVolDistribution • Ion: PICVolDistribution Model 2: • Electron: GlobalMaxwellBoltzmannVolDistrib • Ion: PICVolDistribution For the two models: • Elec Dt: 6.7E−06 s, Elec Duration: 6.7E−06 s, Ion Dt: 2.0E−04 s, Ion Duration: 2.0E−04 s • Plasma time steps: Plasma Dt: 5.0E−05 s, Plasma Duration: 1.0E−06 s	Results/ SPIS_NRC_SphereChargingLDB.xls (sheet PhysicalParam & Numerical params)
Electric field	Boundary condition on external boundary: Pre-sheath mimic (V ~1/r²) Model 1: Linear Poisson solver Model 2: Non-linear Poisson solver	Results/ SPIS_NRC_SphereChargingLDB.xls (sheet PhysicalParam)
Spacecraft	conductive material (ITO) circuit integration C_{sat} = 1.0 E-10 F	
Simulation	Simulation time steps for the two models: Simulation Dt: 1.0E−03 s; Simulation Duration: 1.0E−02 s; Simulation Dt init: 1.0E−04 s	Results/ SPIS_NRC_SphereChargingLDB.xls (sheet Numerical params)
Secondary particles	N/A	

Description / Inputs

Ref : SPIS_NRC_SphereCharging_case1_TDS2 — version : 1.1
Author : JC Mateo-Vélez, B. Rivière — date : 28/08/2012

SPIS Non Regression Case - Technical Data Sheet 2

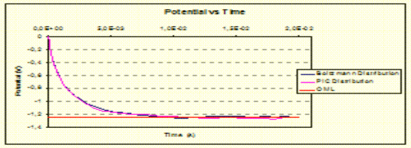
Test case name	Charging of non-emitting absorber in Maxwellian Plasma – Large Debye Length (Radius/Debye_length=0.5)		
Summary	Determination of the equilibrium potential of a spherical probe in large Debye length regime for two electron distributions (PIC and Boltzmann). Ions follow a PIC Distribution. Reference data from OML (Orbital Motion Limit) and Laframboise.		
SPIS version	4.3.2		
OS	Linux – Auriga (ONERA)		
Date of creation	19/04/2012		
Author	JC Mateo-Vélez(ONERA/ DESP): mateo@onera.fr B. Rivière (ONERA/ DESP): benjamin.riviere@onera.fr		
Modification date	28/08/2012	Reasons of change	- Adding the number of super-particles in TDS2 - Adding all the time steps - Filling in the table for improvements/differences

Results

→ Directory: Results/SPIS_NRC_SphereChargingLDB.xls (sheets Simulation and proberatio_0_5)

Floating potentials:

Model	PIC-electron / PIC-ion	Boltzmann-electron / PIC-ion
Final potential: SPIS (V)	-1.251	-1.248
Final potential: OML (V)	-1.25	-1.25
Error (%)	0.9	0.3

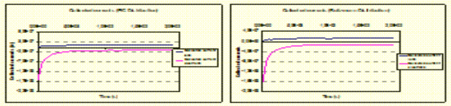


Currents:

Model	PIC-electron / PIC-ion	Boltzmann-electron / PIC-ion
Collected ion current : SPIS (A)	1.32 E-07	1.33 E-07
Collected ion current : Laframboise at OML potential (A) (*)	1.35 E-07	1.35 E-07
Error ion current (%)	2.6	1.8
Collected electron current : SPIS (A)	-1.32 E-07	-1.37 E-07
Collected electron current : Laframboise at OML potential (A) (*)	-1.35 E-07	-1.35 E-07
Error electron current (%)	2.2	1.6

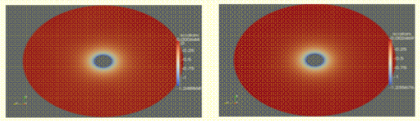
… theory, by … table which … of 2.5: I/I_0 ≈

Outputs / Comparison



→ Other results :

3D data analysis (potential and charge density at the end of the simulation) in results/PIC/vtk for PIC distribution or results/Boltzmann/vtk for Boltzmann distribution.



Final plasma potential in volume for full PIC distribution (left) and Boltzmann-PIC distribution (right)

2D data analysis in results/PIC/2D for PIC distribution or results/Boltzmann/2D for Boltzmann distribution.

Super-particles number

Number of super-particles	At the beginning: PIC-PIC distributions	At the beginning: PIC-Boltzmann distributions	At the end: PIC-PIC distributions	At the end: PIC-Boltzmann distributions
Electrons	184 000	Not supplied	651 000	Not supplied
Ions	184 000	184 000	677 000	184

Performances

CPU Time:

Model	PIC-electron / PIC-ion	Boltzmann-electron / PIC-ion
CPU Time (min)	547	72

Conclusion and perspectives

- Conclusion
  - All the test cases lead to satisfactory results
  - The most challenging simulations concern Child Langmuir case and the case with small Debye lengths
  - Large CPU time necessary for 2 or 3 simulations (PIC population)

- Work pending
  - Automation of cases running by non-regression procedure (Spis5)
  - Delivery to community

- Perspectives
  - Extend the number of cases