Solar Orbiter
SPIS simulation

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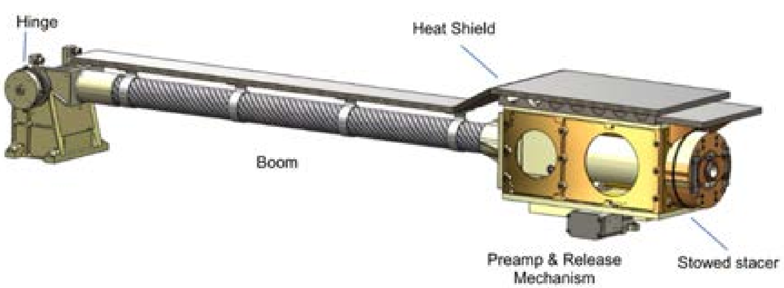
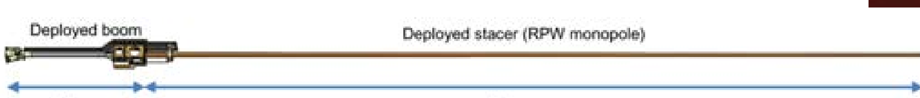
21st SPINE meeting - 18-19 May 2015, ESA HQ

- ESA mission with NASA participation
- Up to 0.28 AU with dedicated in-situ & remote sensing instrumentation
- Out of ecliptic observations
- M-class ESA Cosmic Vision (oct. 2018)

➢ Moving parts (panels, High Gain antenna TBC)

➢ Thermal environment : up to 10 Solar constants : antennas can reach up to 500-600 ° C.





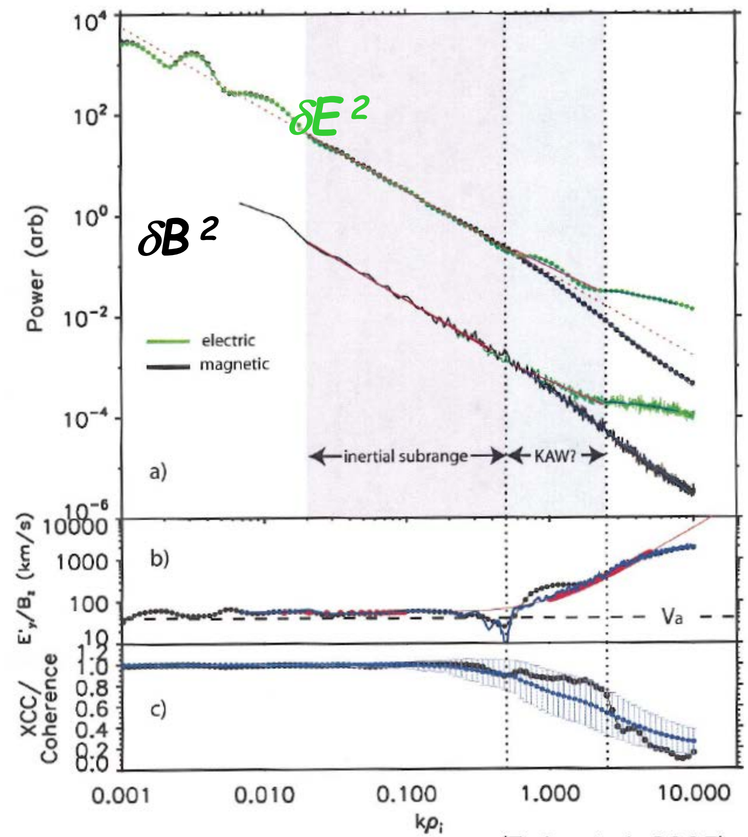
Need to observe electric field associated to Alfvénic fluctuations…

Poynting flux $S = \delta E \times \delta B/\mu_0$

Courtesy S. Bale

Cluster measurements of the E field of solar wind turbulence show that:

1. The cascade is Alfénic, E & B strongly correlated
2. Short λ E field power is enhanced
3. E/B ratio is consisyent with Alfénic inertial range and evolution to KAW at short λ
4. Density (S/C pot.) spectrum is $k^{-5/3}$

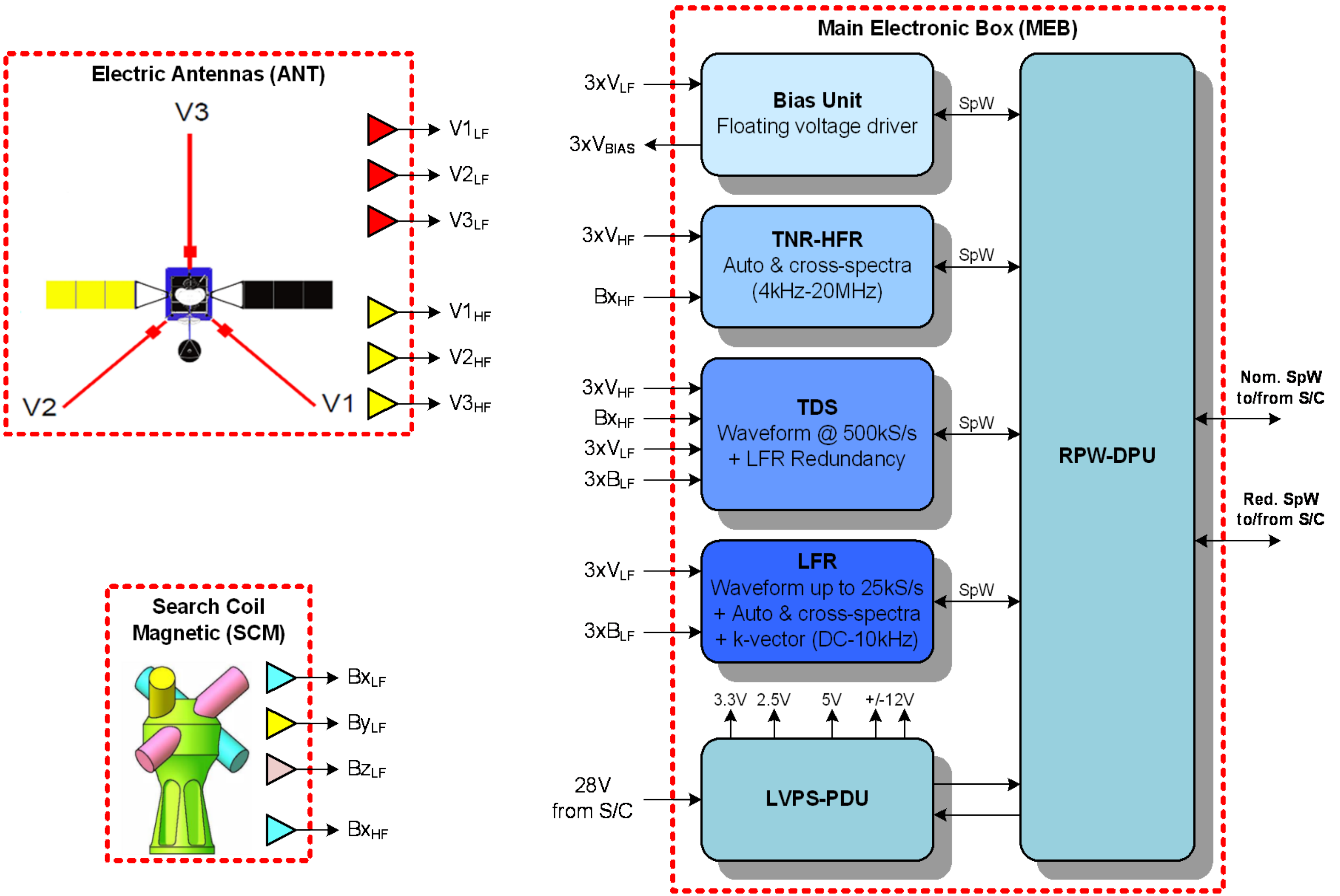


(Bale et al, 2005)

Requirements :

~0.1 to ~500 mV/m with a sensitivity of 0.01 mV/m

RPW (Radio & Plasma Waves) Instrument block Diagram



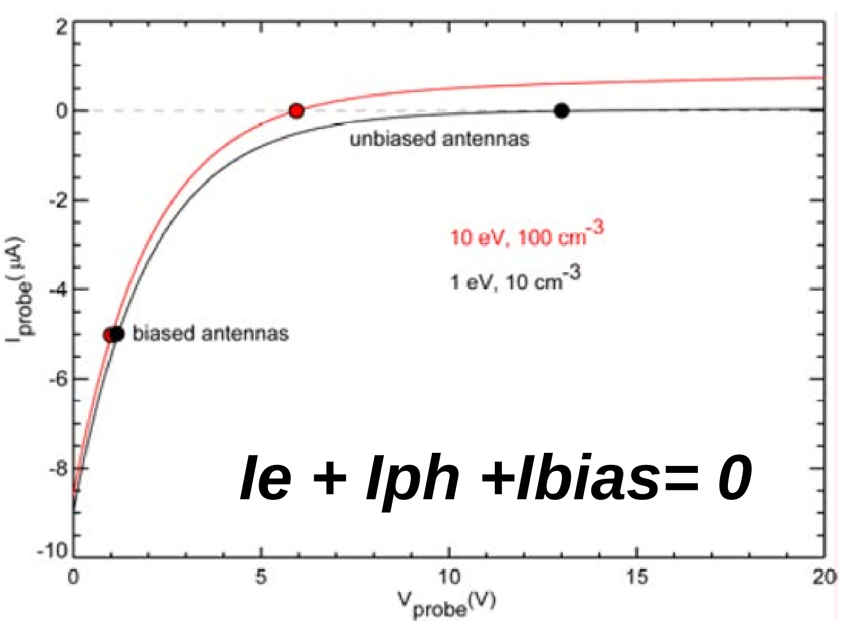
How to measure an electric field with RPW

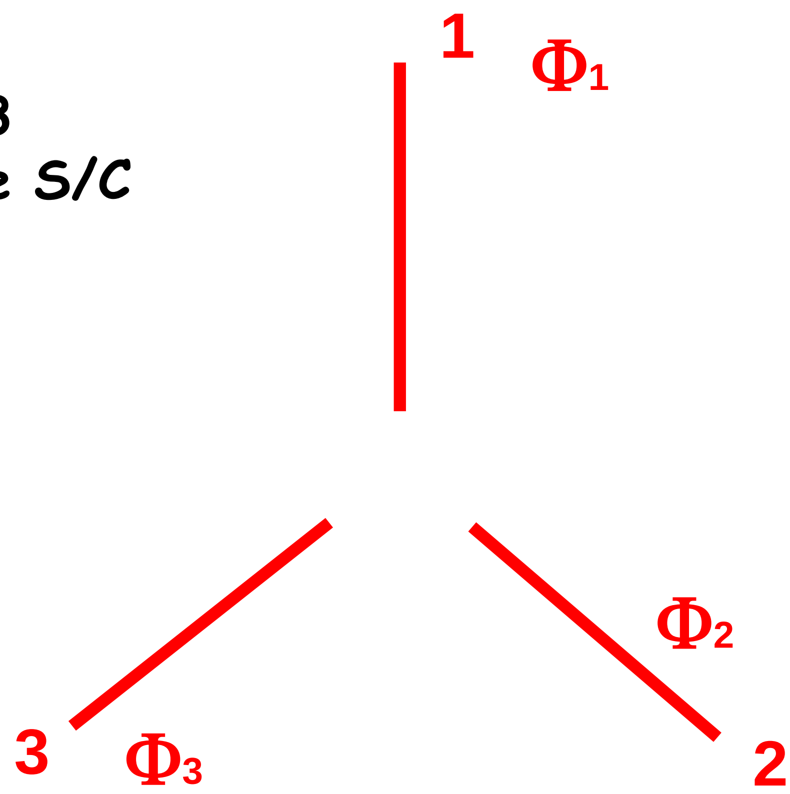
If we have :

- Equal illumination for 1, 2 & 3
- Symmetry with respect to the S/C
- Biasing on the probes

Then $\Phi_1 = \Phi_2 = \Phi_3$

and $\Phi_1 - \Phi_2 = 0$

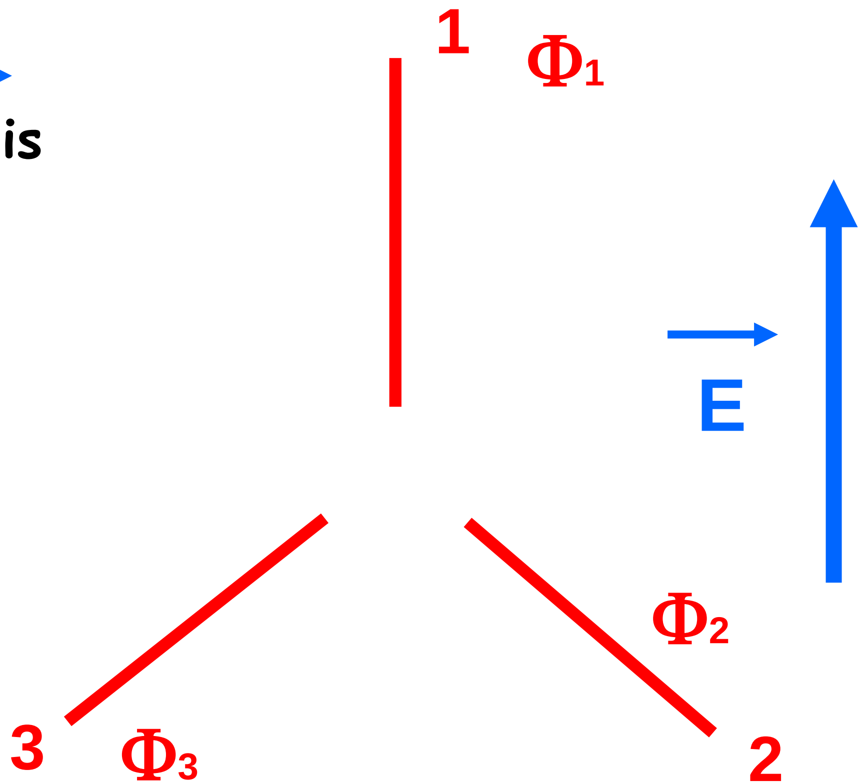




How to measure an electric field with RPW

If an external electric field $\vec{E}$ is applied then :

Then $\Phi_1^* \neq \Phi_2^*$



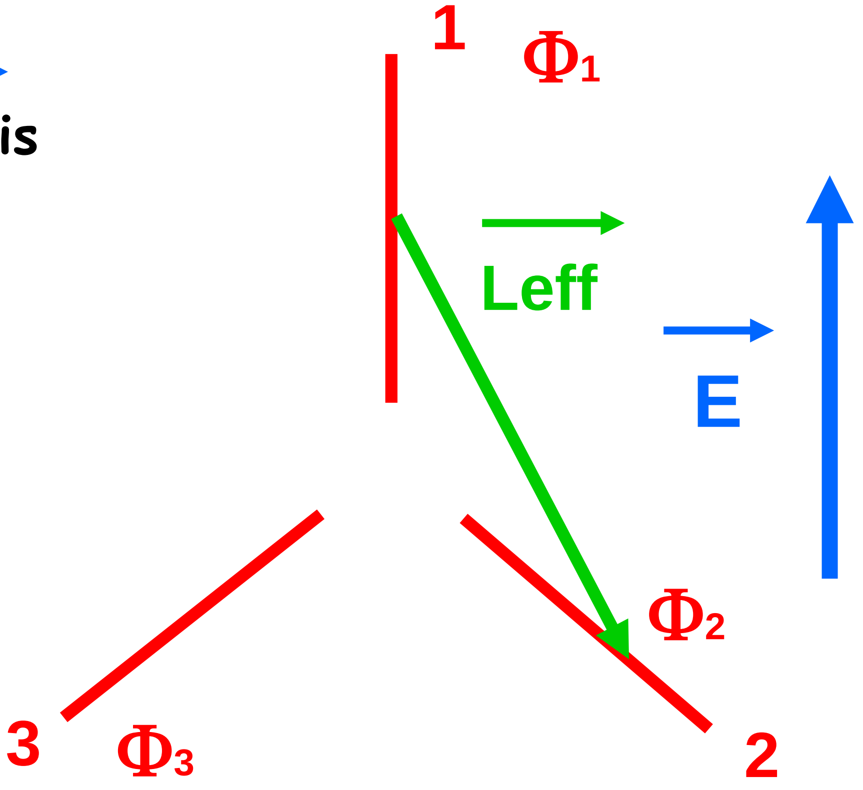
How to measure an electric field with RPW

If an external electric field $\vec{E}$ is applied then :

Then $\Phi_1^* \neq \Phi_2^*$

Actually $\Phi_1^* - \Phi_2^* = \delta\Phi E$

With $\delta\Phi_E = \vec{E} \cdot \vec{Leff}$



$\vec{Leff}$ can only be determined by simulation

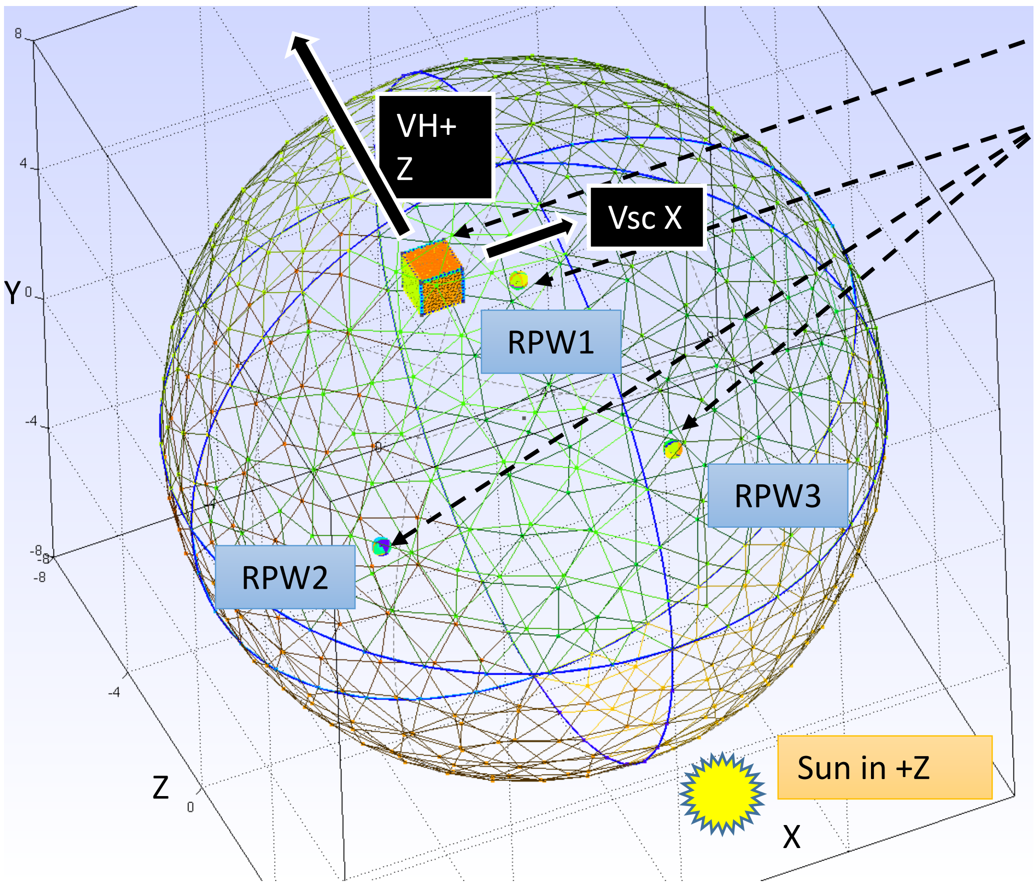
Preliminary work

- 1st idea: compare 3D/1D modeling of the antennas, hoping to valid 1D representation (3D remains costly due to high meshing resolution)
  - This allowed to improve 1D modeling (correction of bugs, enhancement of the solver… see further)
  - But 1D modeling remains an approximation. Not possible to obtain same potential on a simple 3D tube (+11V) and a 1D wire (+15V) : 36% of difference
  - 1D representation not validated in this case -> further quantitative results have to be considered with caution, qualitative results are supposed to be correct

First approximation of the RPW configuration

- In order to simplify the case
  - Omission of Solar Orbiter SC body –> observation of charging on RPW only. But it is not possible to have only 1D wires in the Simulation box. Thus: consideration of a conductive cube being the electrical ground. Tests showed that its size of 10 cm was to small compared to the 5m long stacers (strong potential fluctuations in this case). Necessity to enlarge the cube (to 1m) and place it 4.4m behind the plane containing the antennas (to limit its influence)
  - Instead of the wires, we first consider 3 spheres of (17 cm radius: ~ same « surface » that the stacers) each placed at the center of the future stacers
  - The simulated environment is the one at 0.28 AU from the Sun (SolO perihelion)

« Spherical antennas » inputs



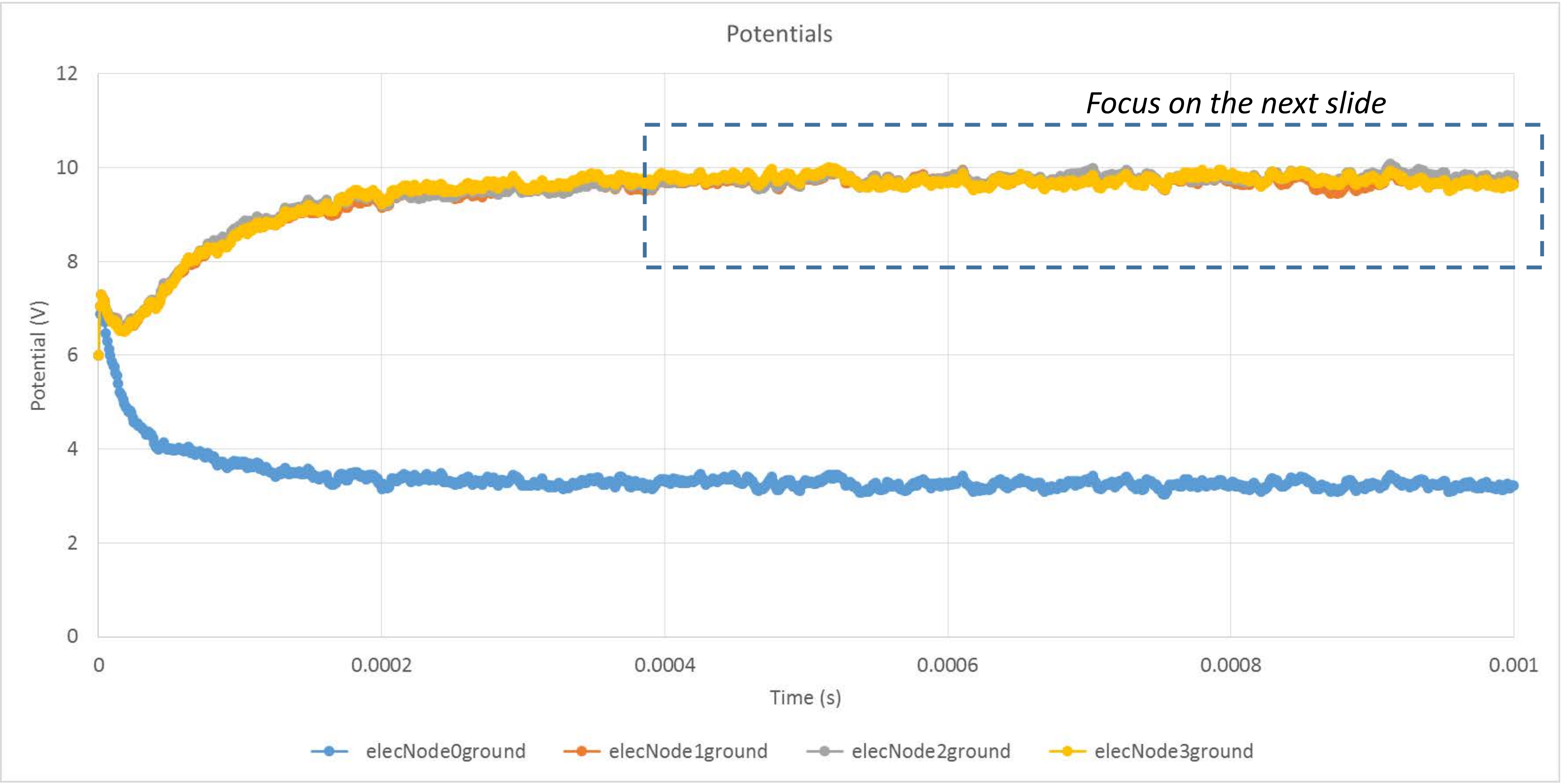
SC body (CFRP) at Z = -4.4m (Csat=10^{-10} F)

3 GOLD spheres in the same Z=0 plane (C between ground and RPW = Csat)

Environment parameters	Values at 0.28 AU from the Sun
Sun flux (# 1 AU)	12.76
Electron and Proton density (m^{-3})	1.04×10^8
Electron temperature (eV)	21.37
Proton temperature (eV)	27
Spacecraft velocity in X direction (m/s)	60000.0
Proton bulk velocity in Z direction (m/s)	-400000.0

- Ions: *H+*, PIC with Maxwellian distribution and drift,
- Electrons: PIC with Maxwellian velocity distribution function,
- Photoelectrons: PIC with Maxwellian velocity distribution function and with a characteristic temperature $k_B T_{ph}$ = 3 eV,
- Secondary Electrons under Electron impact (SEE): PIC with Maxwellian velocity distribution function and with a characteristic temperature $k_B T_{SEE}$ = 2 eV, backscattered electrons with 2/3 of their initial energy,
- External boundary conditions: Fourier, $1/R^2$ decrease of potential

Reference test: spheres without B and VxB



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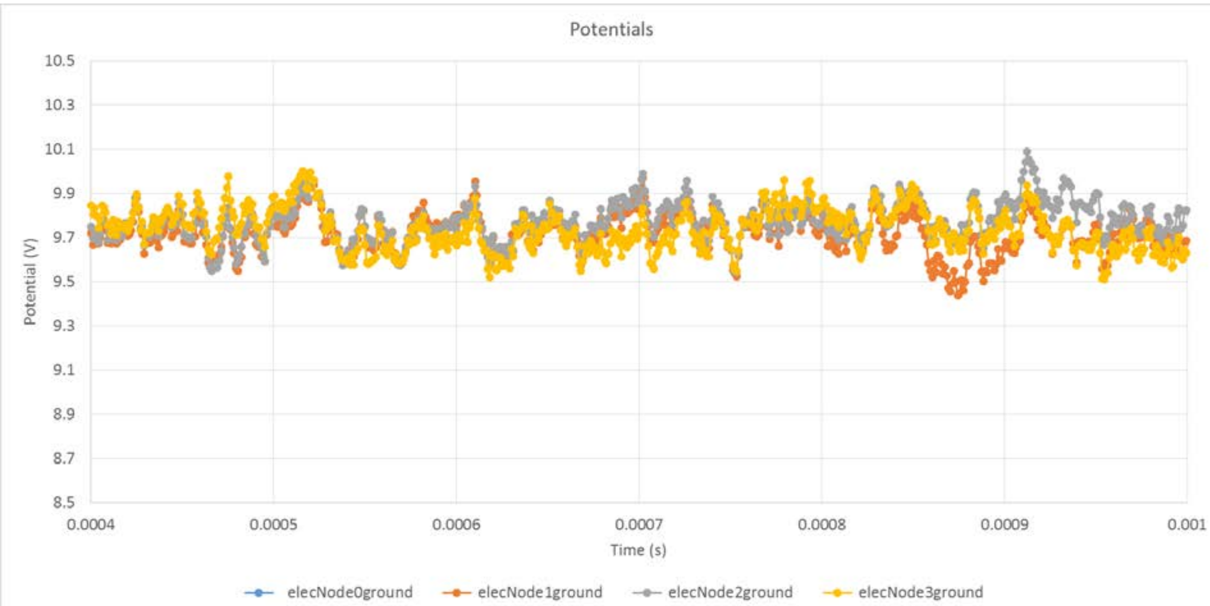


After an uncountable number of tests with various geometries and numerical configurations: we finally obtained a stable and workable simulation…
Considering the system configuration, all spheres should be charged at the same potential. It is the case here.

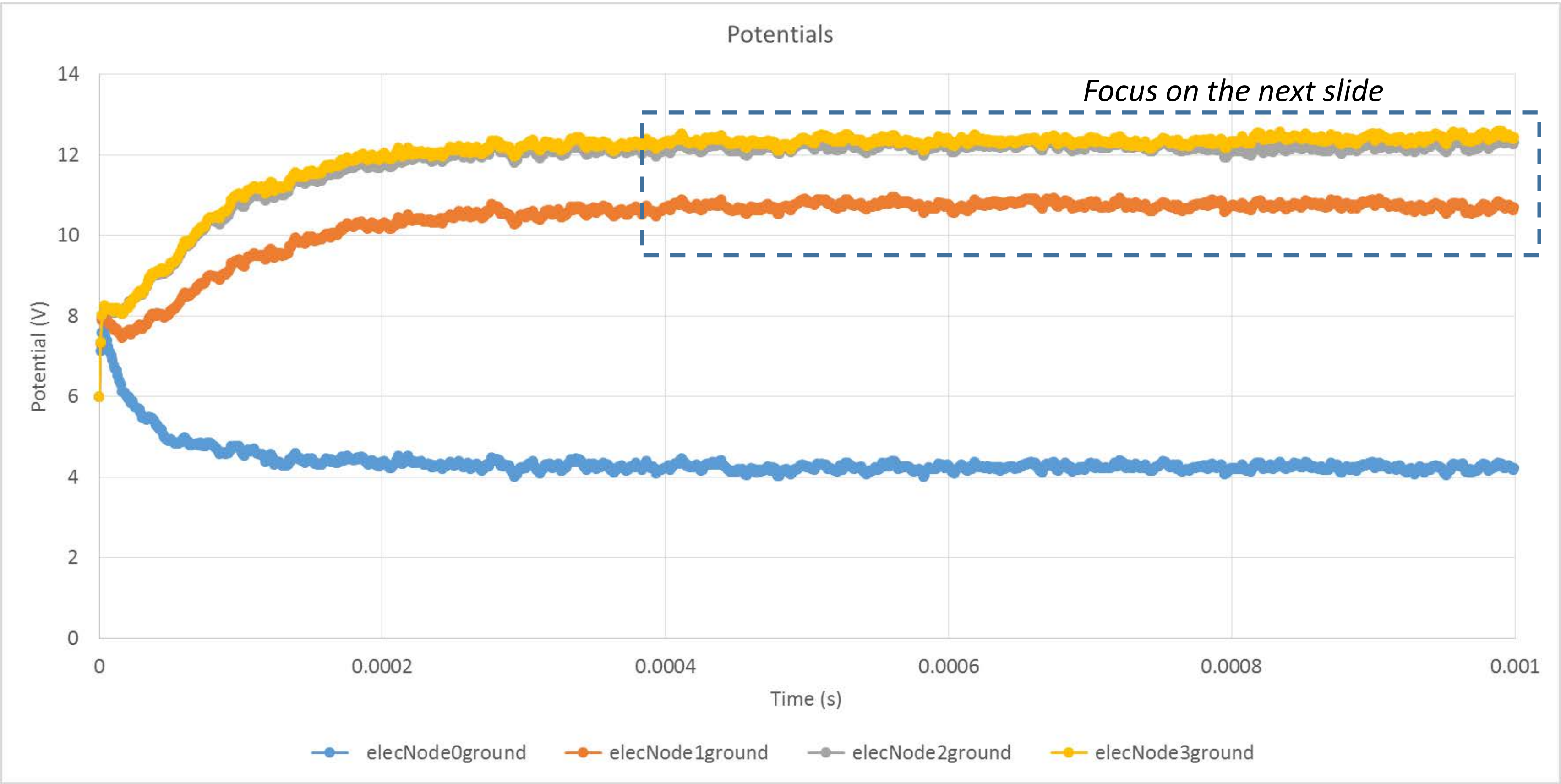
Following values are averaged over the time period selected on the left:

In average	Node 0: SC ground	Node 1: RPW1	Node 2: RPW2	Node 3: RPW3
Potential ϕ (V)	3.25	9.72	9.77	9.74
Standard deviation σ (V)	0.08	0.09	0.09	0.10

Case1: spheres with B and VxB

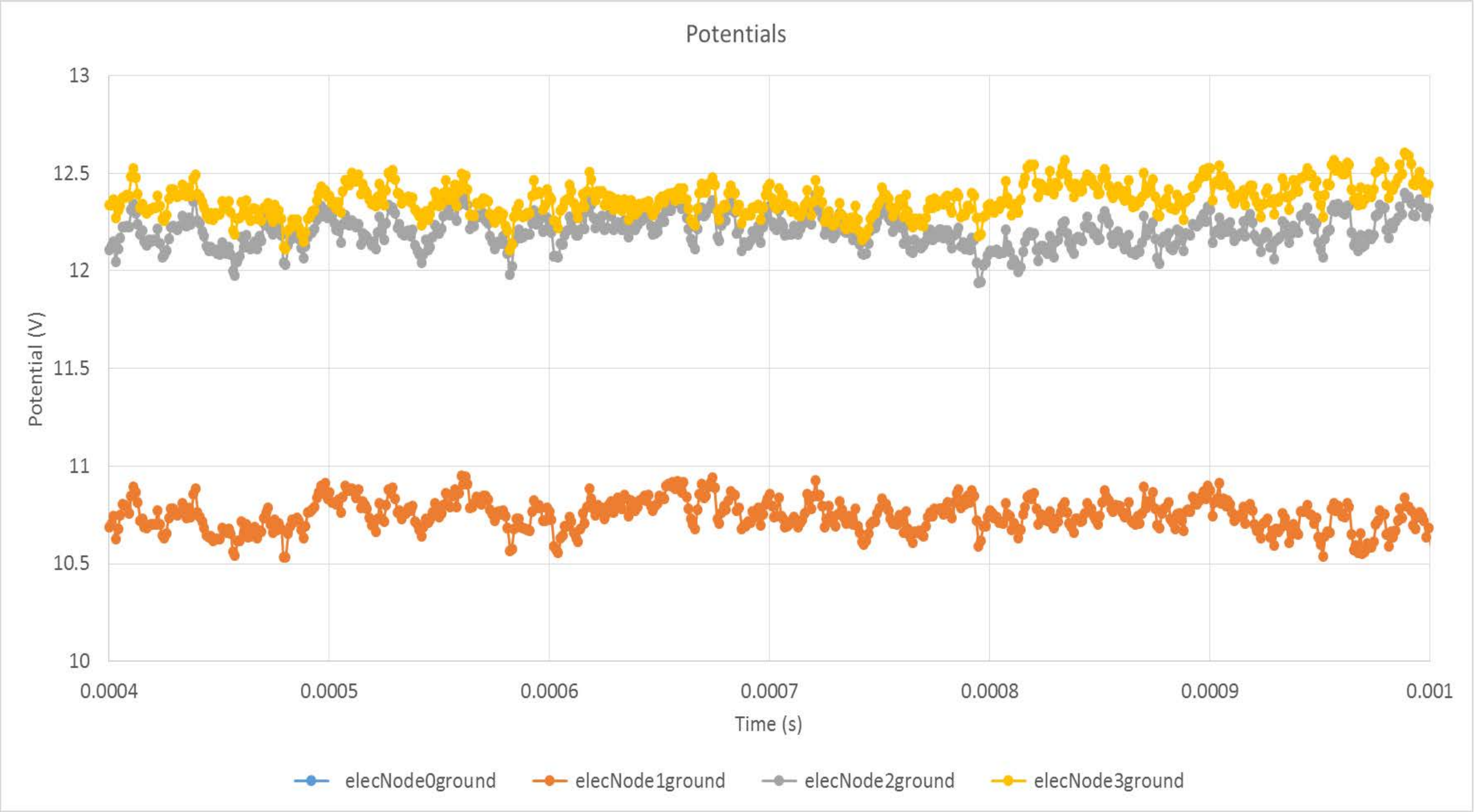
- Including a non-realistic magnetic field Bz = -4 µT
- Simulating a physical case using ***B*** fixes the reference basis of the simulation where $\boldsymbol{V}_{\boldsymbol{plasma}}$ = **0**. In this basis we have to set the spacecraft velocity in the reference of the plasma ***V***, combining both plasma bulk velocity (related to the solar wind velocity) and the satellite motion over its orbit. In this case, $\boldsymbol{V}_{\boldsymbol{protons}}$ = **0,** and for the spacecraft $V_{SC\_X} = 6\times10^4$ m/s and $V_{SC\_Z} = 4\times10^5$ m/s
- Finally the resulting VxB electric field is $\boldsymbol{E} = E_Y\,\boldsymbol{e_Y}$ = 240 mV/m
- As E = -Δϕ/ΔL, with L the effective length between spheres and $\Delta\phi_{1\text{-}2} = \phi_1 - \phi_2$… The interest is to measure Δϕ between spheres to find out L, knowing the imposed E field.

Case1: spheres with B and VxB



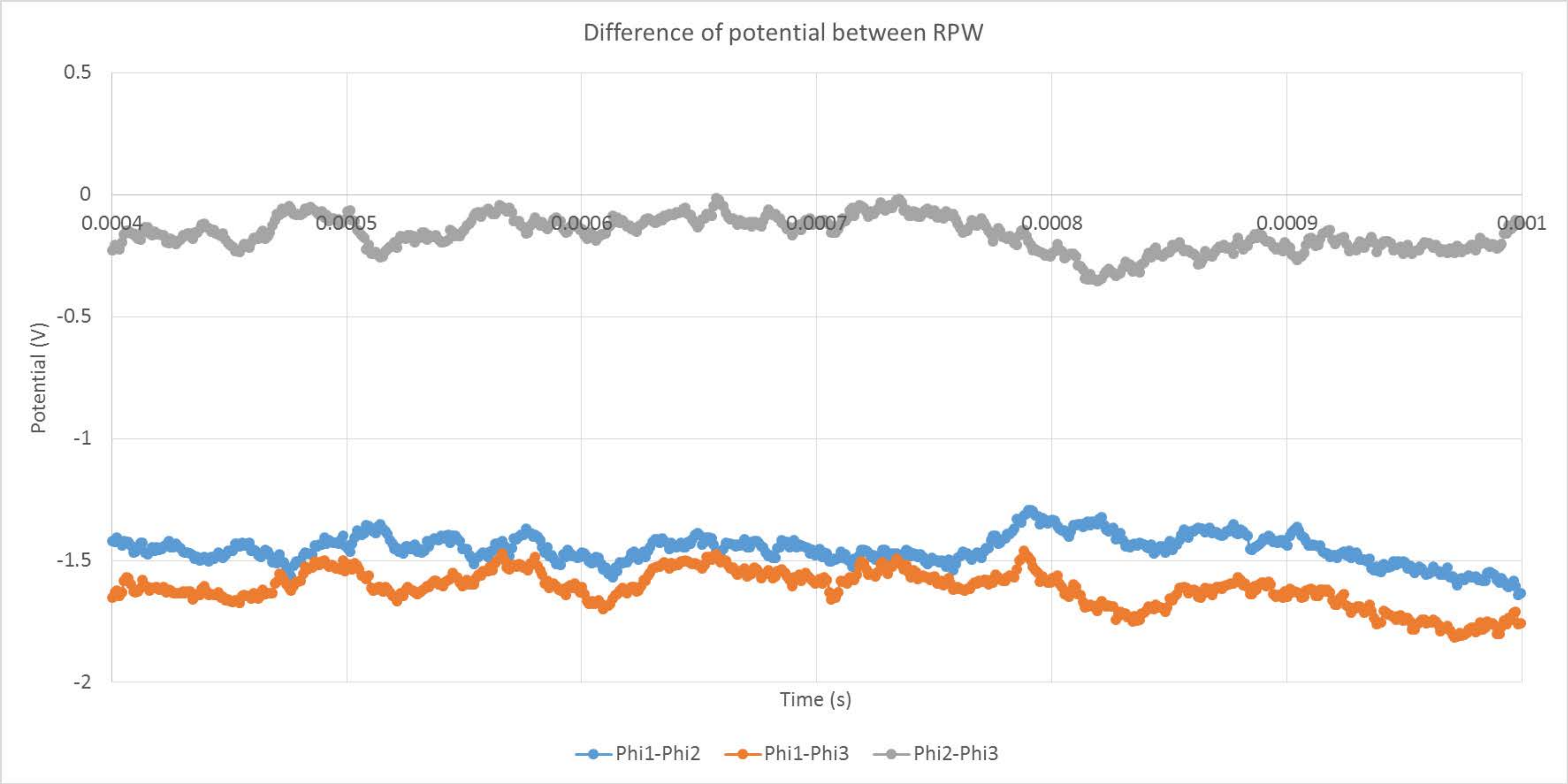
Case1: spheres with B and VxB

In average	Node 0: SC ground	Node 1: RPW1	Node 2: RPW2	Node 3: RPW3
Potential ϕ (V)	4.24	10.75	12.20	12.36
Standard deviation σ (V)	0.07	0.08	0.08	0.08



In average	$\Delta\phi_{1\text{-}2} = \phi_1 - \phi_2$	$\Delta\phi_{1\text{-}3} = \phi_1 - \phi_3$	$\Delta\phi_{2\text{-}3} = \phi_2 - \phi_3$
$\Delta\phi$ (V)	-1.45	-1.61	-0.16
Standard deviation σ of $\Delta\phi$ (V)	0.06	0.07	0.07

With this geometry: ΔY between spheres 1 and (2-3) is -6,73m → with E=240mV/m it gives **$\Delta\phi$(theor.) = -1.61V**



Case2: 1D wires without B and VxB

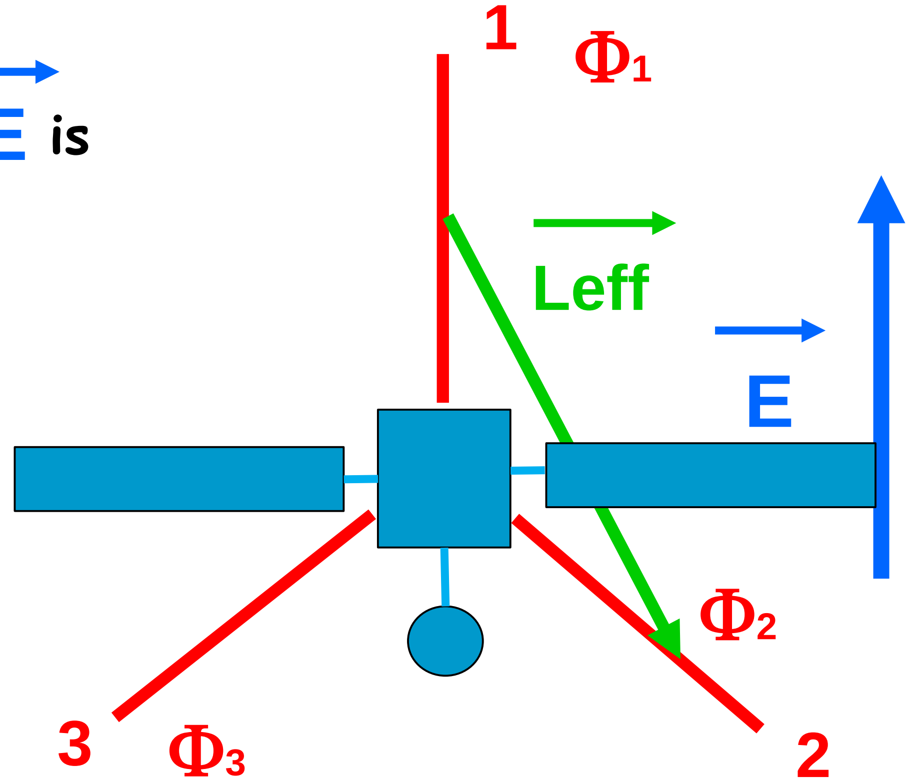
- TO BE COMING SOON…
- This geometry, with and without B, has been used for simulations but I have problems interpreting the results due to various potential values depending on the output provided by SPIS (potentials.txt, VTK on different reference frames, 2D results….)
- More complex simulations with more developed geometries have also been launched but need to be readjusted with bigger SC body.

If an external electric field $\vec{E}$ is applied then :

Then $\Phi_1^* \neq \Phi_2^*$

Actually $\Phi_1^* - \Phi_2^* = \delta\Phi E$

With $\delta\Phi_E = \vec{E} \cdot \overrightarrow{Leff}$

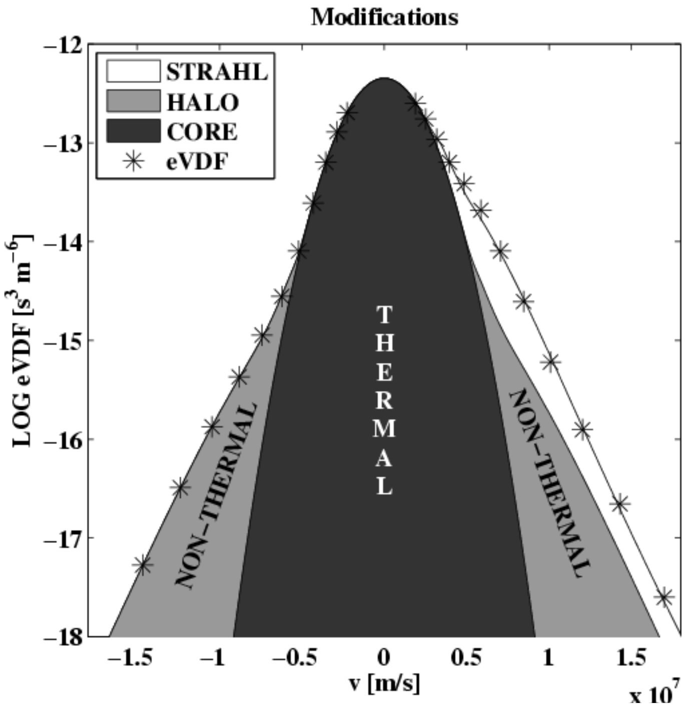


Effects of the S/C body on $\overrightarrow{\text{Leffs}}$ (1 2 & 3) ??

+ addition off the antennas Biasing currents in SPIS

Radial evolution of electron distribution functions

Stverak et al., JGR, 2009



Core : bi-Maxwellian * flat-top

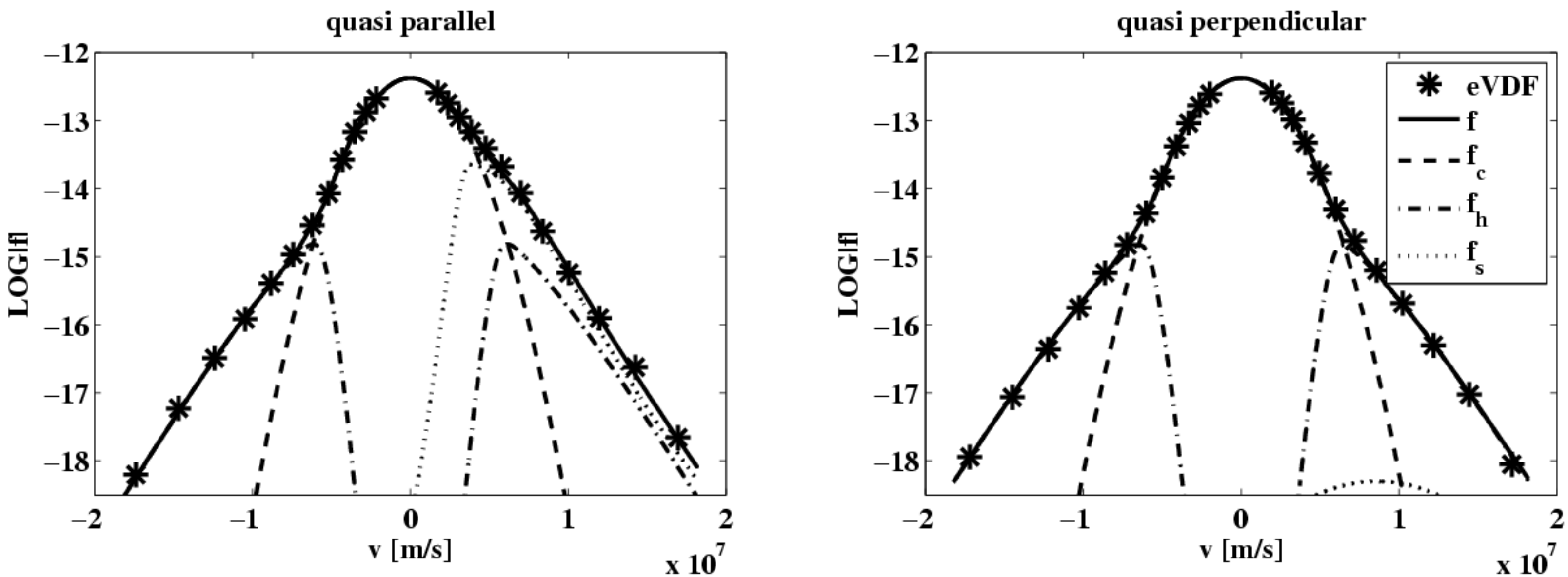
$$f_c = A_c \exp\left[-\frac{m}{2k}\left(\frac{1}{T_{c\perp}}v_\perp^2 + \frac{1}{T_{c\|}}(v_\| - \Delta_c)^2\right)\right],$$

Halo : bi- Kappa * (1-flat-top)

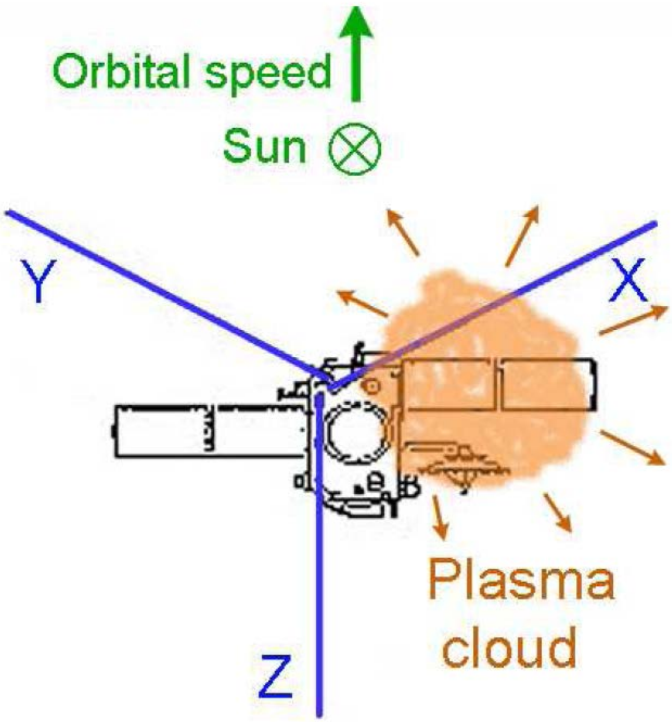
$$f_{h,\kappa} = A_h\left(1 + \frac{m}{k(2\kappa_h - 3)}\left(\frac{v_\perp^2}{T_{h\perp}} + \frac{v_\|^2}{T_{h\|}}\right)\right)^{-\kappa_h - 1},$$

Strahl : bi- Kappa * (1-flat-top) from antisunward dir.

$$f_s = A_s\left(1 + \frac{m}{k(2\kappa_s - 3)}\left(\frac{v_\perp^2}{T_{s\perp}} + D\frac{(v_\| - \Delta_s)^2}{T_{s\|}}\right)\right)^{-\kappa_s - 1}$$

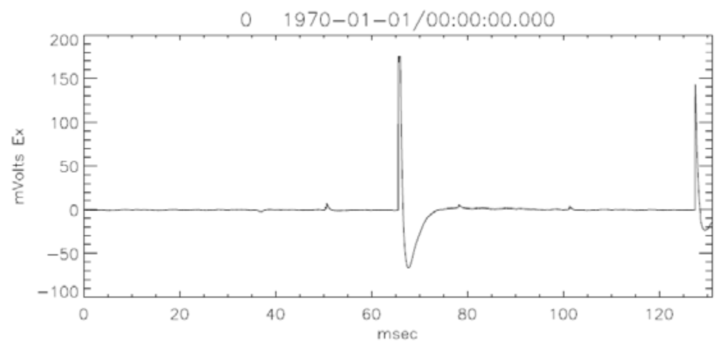


Possible simulations for Dust/Spacecraft interactions



Released charge : $Q \simeq 0.7 m^{1.02} v^{3.48}$

Induced voltage pulse on S/C of capacitance C : $\delta V \sim -Q/C$



Very large flux on Stereo

→ *A nanoparticle @ 300 km/s* ~ *a grain of mass 10^4 greater @ 20 km/s*

What is exactly the interaction Plasma cloud / ambient plasma / spacecraft ?

Picked-up by the -VXB field

l'Observatoire de Paris | LESIA

RPW

Numerical issues related to the SPIS-5 software during this work (by S. Guillemant):

1) Discovery of a bug concerning photo-emitted currents by 1D antennas (a thin wire consideration of an antenna). A π factor was present in the code whereas it should not. The surface of emission was implemented as 2πRL (R being the radius of the antenna and L its length). This surface should be 2RL. This has been found when comparing simulations of 3D/1D antennas which did not provided us with the same potentials on the surfaces (SPIS 5.1.0).
2) Impossibility for SPIS to compute when there are only thin wires in the simulation box. A small Spacecraft body had to be implemented in the simulation.
3) Discovery of a bug concerning the SPIS solver « dichotomy method », related to the particle transport when including a magnetic field and the presence of thin wires within the simulation box (5.1.2).
4) Discovery of a bug on materials in version 5.1.2
5) New patch to solve simulations issues with a magnetic field: this patch uses the RKCK solver in the vicinity of the wires and the dichotomy method elsewhere. However it did not worked.
6) New corrections on photoelectron emission on a wire with and without a magnetic field, due to the electric field around a wire (singular/regular part of the field).
7) New corrections on the RKCK solver performances (due to thin panels calculations, even if they were not considered in the simulation). Computation was too heavy and long (5.1.3 Snapshot).
8) New correction on simulation blocking issues: it occurred that some particles had bad or erroneous positions but were still tried to be pushed by the solver. Now those particles are identified and deleted before the particle pushing step (SVN 860).
9) Strong meshing issues when trying to model more precisely the RPW elements (proximity of the wires with the pre-amplifier and the sunshield of the antenna). This is not due to SPIS but to the geometric configuration of the real RPW system. Elements in SPIS had to be more separated and the mesh size adapted to respect the meshing constraints for SPIS and GMSH.
10) Impossibility for SPIS to handle an electrical circuit for the satellite containing two elements (a resistance R and a capacity C) mounted in series (as it should be the case between the pre-amplifier and the RPW antenna). It lead to strong difficulties for the solver. We need to neglect R.
11) Impossibility for SPIS to handle in the electrical circuit capacities of several orders of magnitude lower than the spacecraft capacity itself. It leads to stability issues. Time steps had to be adapted.
12) New version of SPIS (5.1.9) allowing to generate biasing currents on wires. It was not possible before and it will be needed for further studies.