RPW Consortium Meeting #19
SPIS Simulations for RPW

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on behalf of Stanislas Guillemant

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KTH, Stockholm

Space Environments and Radiation Effects on EEE components
Final presentation

NUMERICAL SIMULATIONS OF SOLAR ORBITER AT ITS PERIHELION: SPACECRAFT CHARGING, EFFECTS ON RPW AND SWA-EAS INSTRUMENTS

Ref.: Assessment of Solar Orbiter surface charging impact on plasma instruments - *ID:* ESA RFP/NC/IPL-PSS/JK/jk/419-2015

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Start and end dates:
14.10.2015 – 31.05.2017

CONTENTS

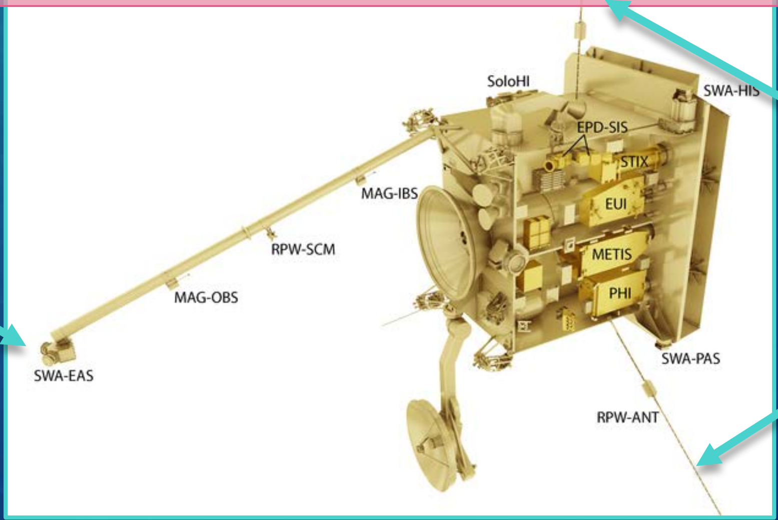
SCIENTIFIC CONTEXT

- **Solar Orbiter**
- ✓ ESA Mission + NASA, launch in 2019
- ✓ Study of the heliosphere, magnetic field, solar wind… in situ and remote sensing instrumentation
- ✓ Orbit varies between 0.9 and 0.28 AU
- ✓ Out of ecliptic observations (25° - 34° max)
- ✓ Moving parts (panels, HGA)
- ✓ Thermal environment: up to 10 Solar constants, antennas can reach up to 500-600° C.

Strong SC/plasma/EM fields interactions which will disturb environment analysis:
- ✓ SC charging
- ✓ Env. reaction
- ✓ SC particle emission
- ✓ Fields

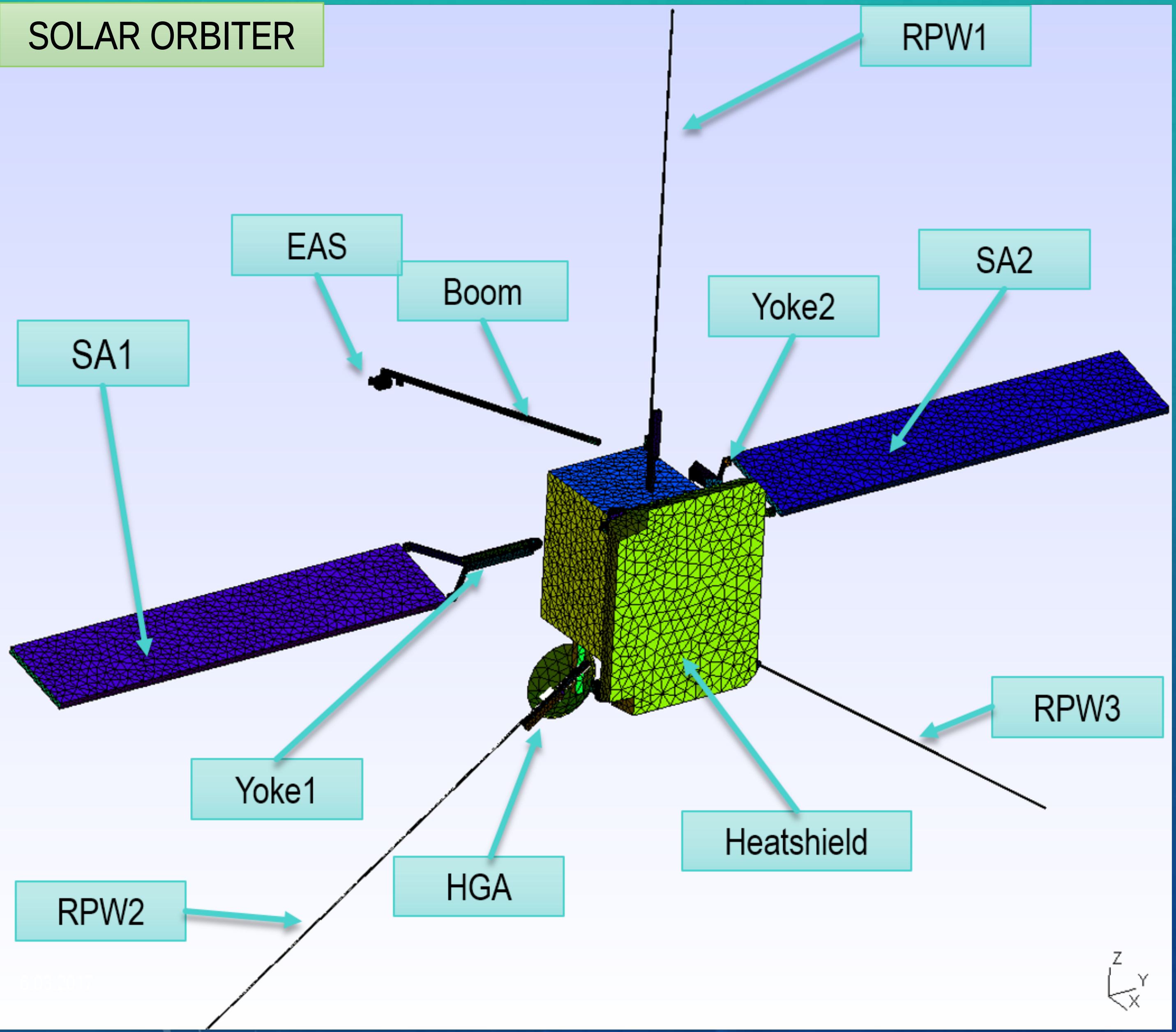
Objective of this study: *1) Evaluate the perturbations on the SC and 2 instrument measurements, through numerical simulations using the SPIS software (Spacecraft Plasma Interaction System: http://dev.spis.org/projects/spine/home/spis)*
2) Train and allow LESIA and MSSL teams to be autonomous for next studies

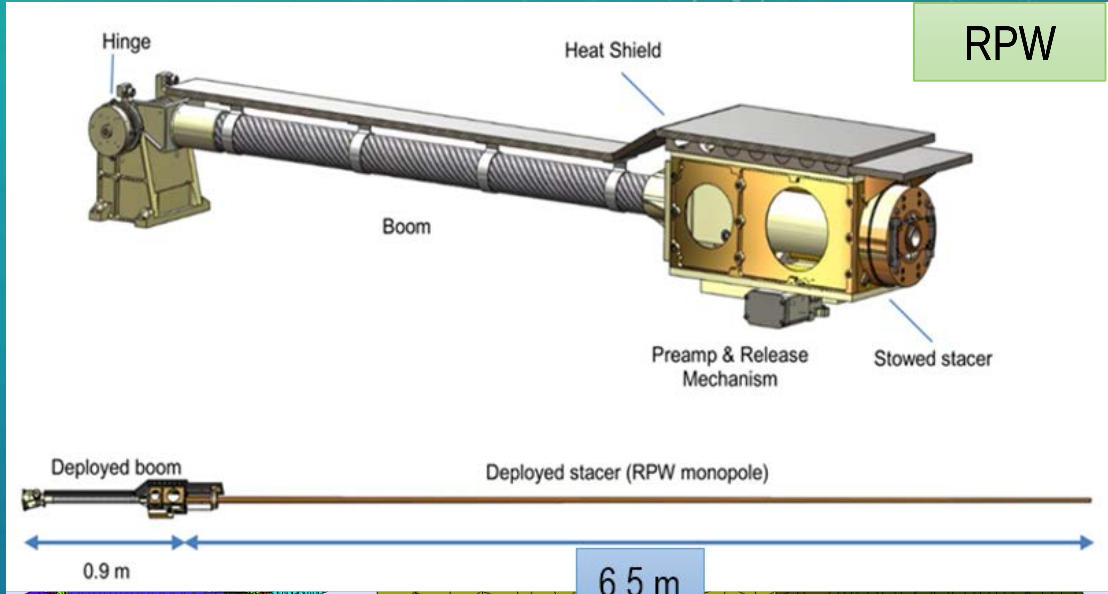
The Electron Analyzer System (SWA-EAS): measure electron bulk properties (N, V, and T) of the solar wind

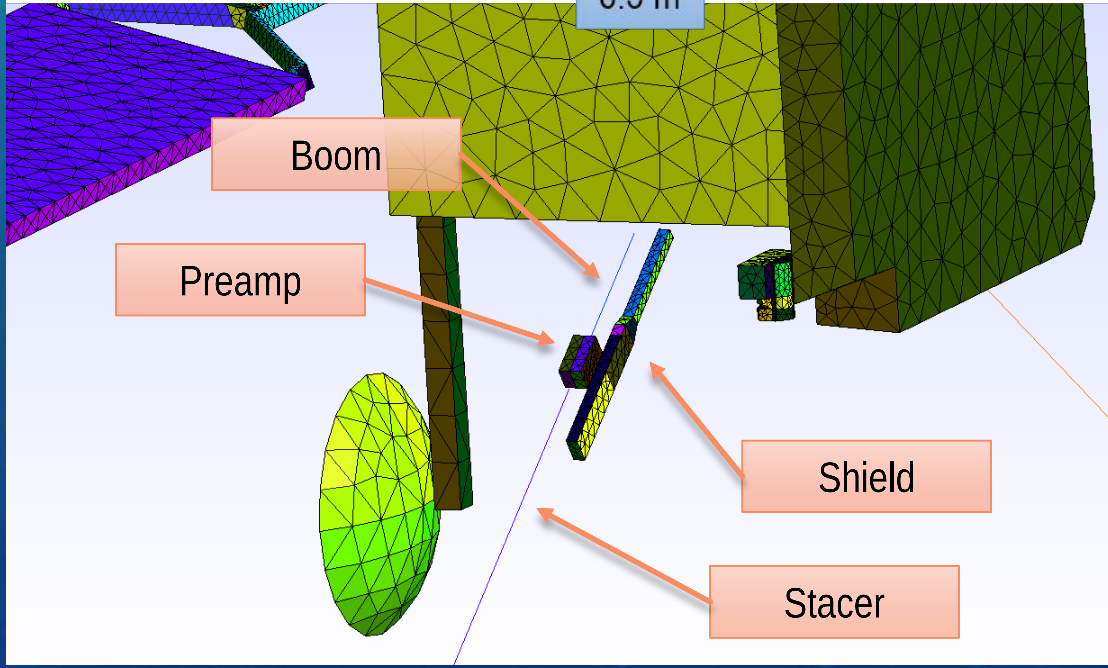


The Radio and Plasma Waves (RPW) experiment: measure B and E fields at high time resolution and determine the characteristics of electromagnetic and electrostatic waves in the solar wind

RPW: SOLAR ORBITER AND RPW LATEST MODEL FOR SPIS



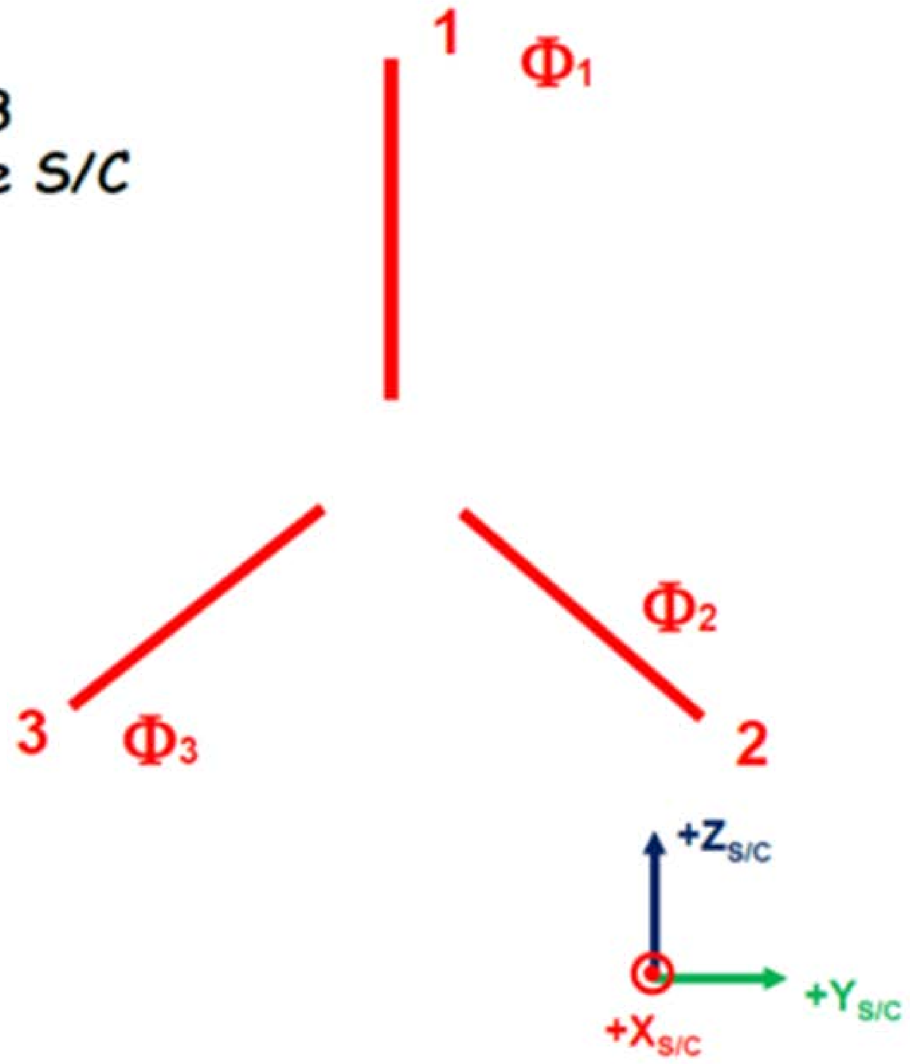




RPW: E FIELD MEASUREMENT PRINCIPLE

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 $\Phi_1 - \Phi_2 = 0$



RPW: E FIELD MEASUREMENT PRINCIPLE

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

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

Actually $\Phi_1^* - \Phi_2^* = \delta\Phi_{12}$

With $\delta\Phi_{12} = \overrightarrow{E1}_2 \,.\, \overrightarrow{Leff}_{12}$

$\delta\Phi_{23} = \overrightarrow{E}_{23} \,.\, \overrightarrow{Leff}_{23}$

$\overrightarrow{Leff}$ can only be precisely determined by simulation

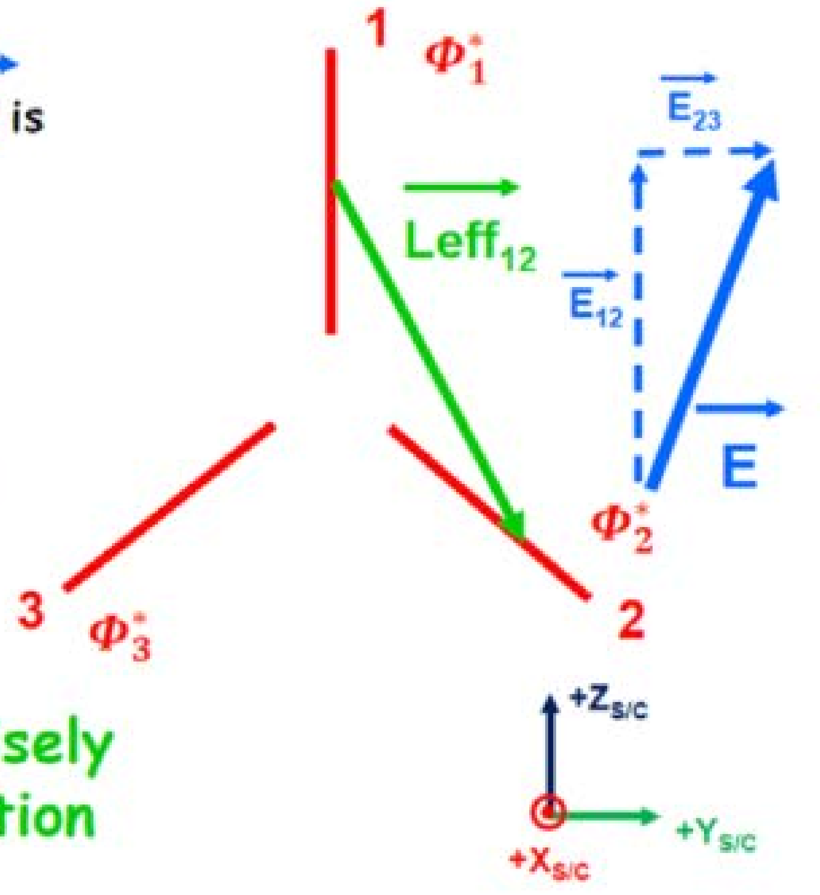


Figure 2

RPW: E FIELD MEASUREMENT PRINCIPLE

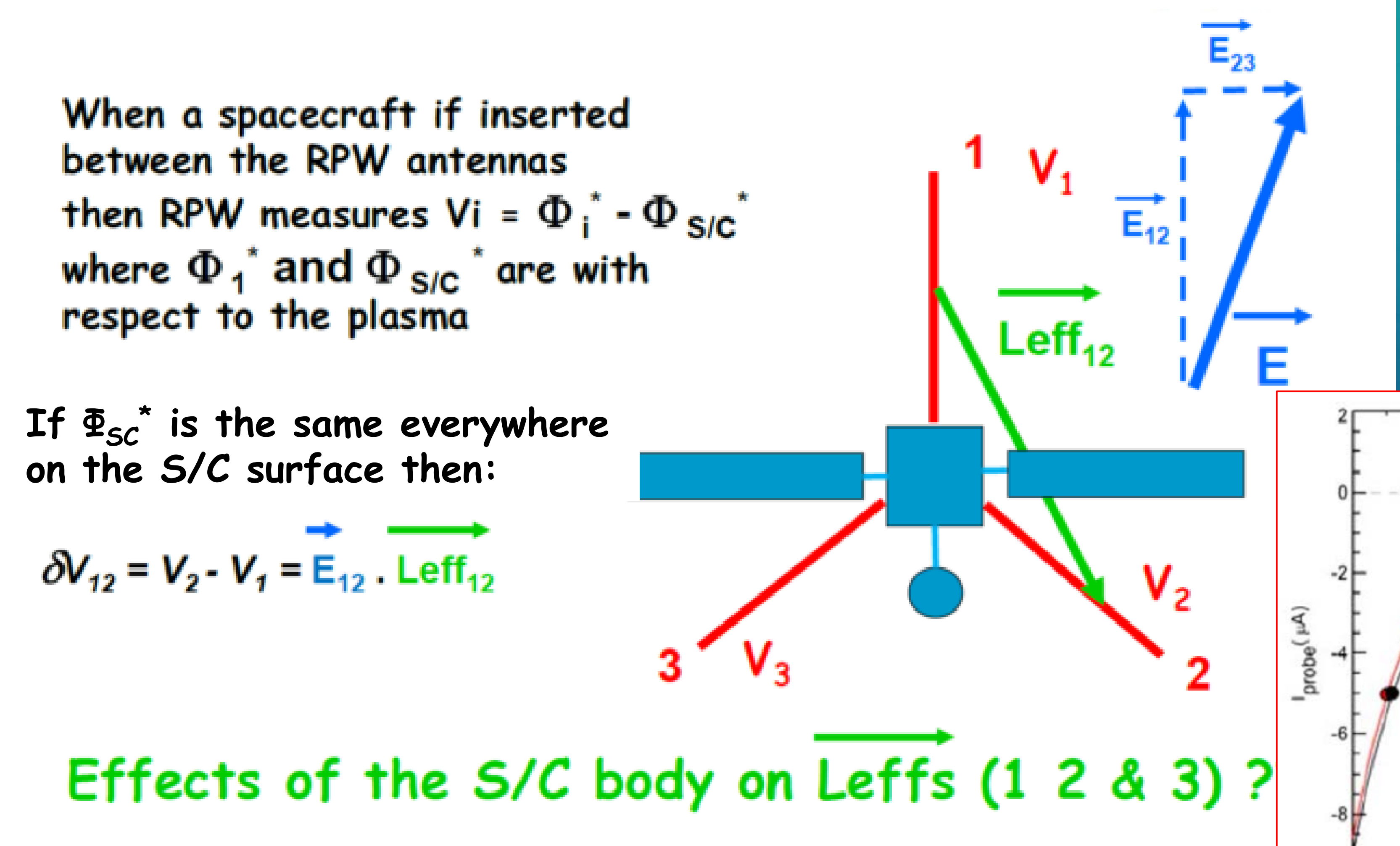
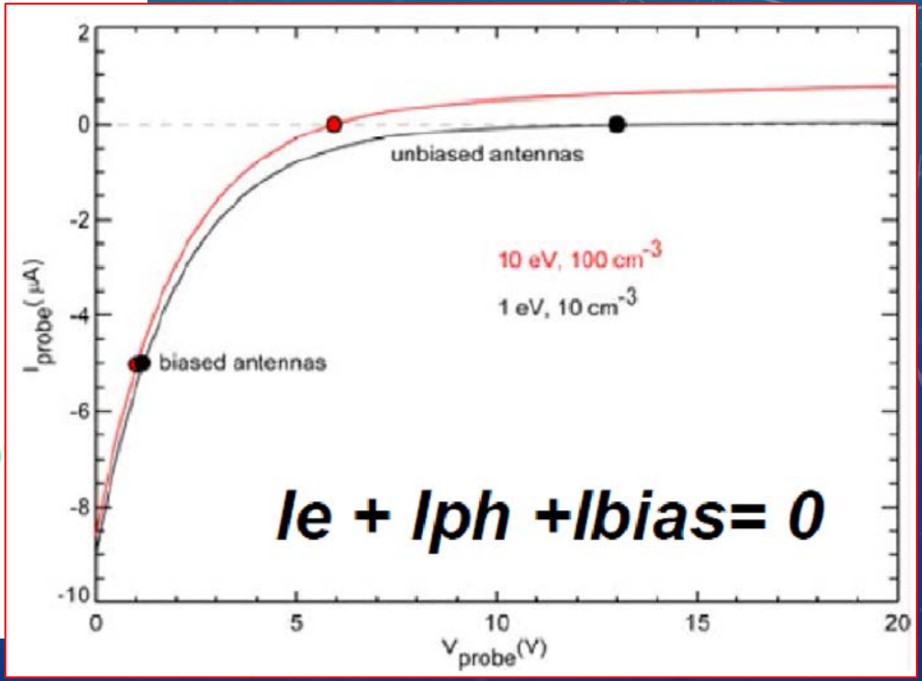


Figure 3

Biasing currents



RPW: PREVIOUS RESULTS WITH OLDER CONFIGURATION

- Older SC & RPW models: gold material on RPW
- Simulation @ 0.28 AU
- PIC populations
- Simulating a physical case using B fixes the reference basis of the simulation where Vplasma = 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
- **Finally a VxB induced electric field is obtained**, *in those cases aligned with RPW1*

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
Proton temperature (eV)	27
Spacecraft velocity in X direction (m/s)	400000
Spacecraft velocity in Y direction (m/s)	-60000
Magnetic field (T)	Varying
Debye length (m)	3.4

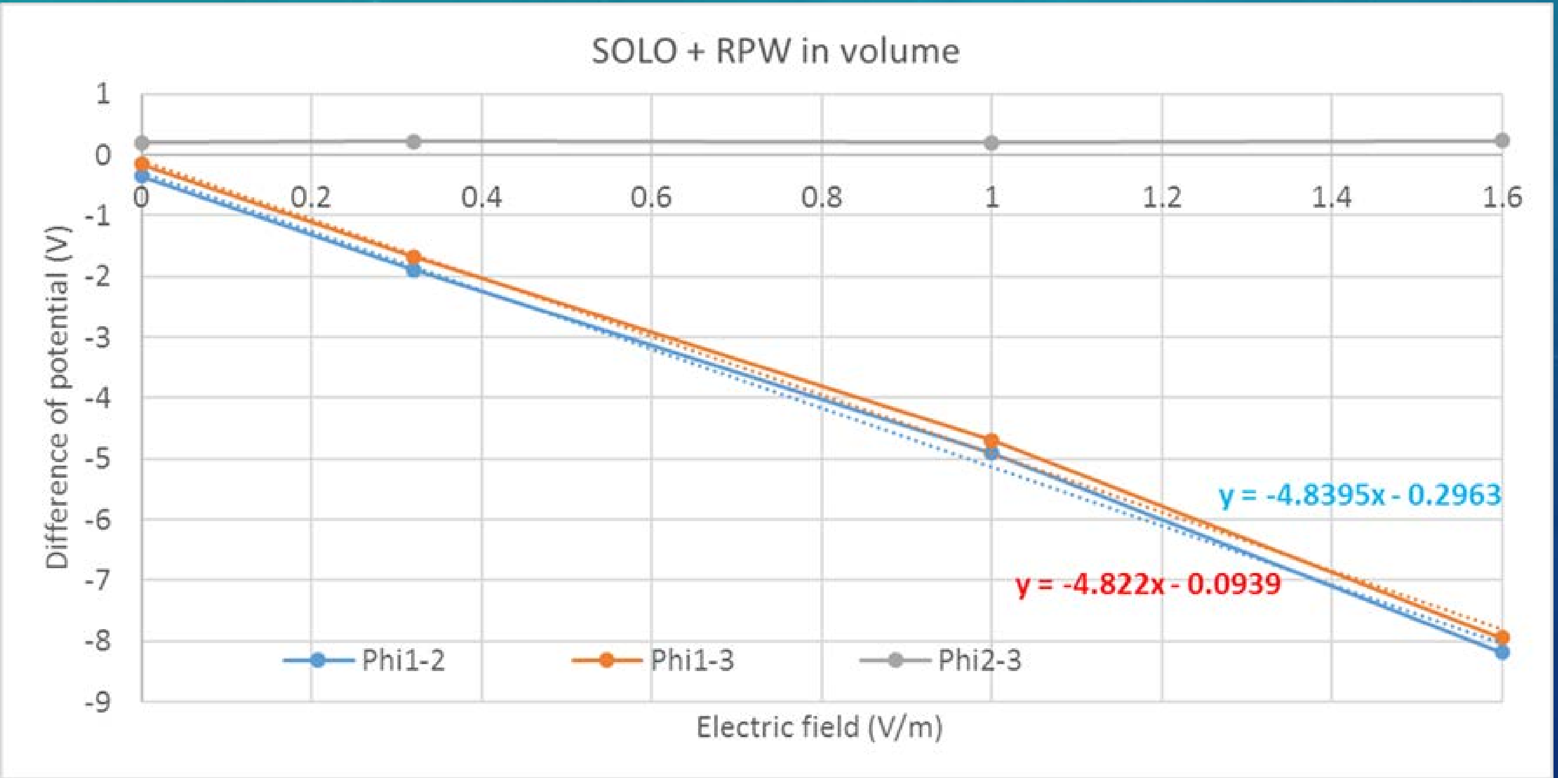
- Ions: *H+*, PIC with Maxwellian distribution and drift,
- Electrons: PIC with Maxwellian velocity distribution function,
- Photoelectrons: PIC with Maxwellian velocity distribution function and with a characteristic temperature $k_B T_{ph}$ = 3 eV,
- Secondary Electrons under Electron/Proton impact (SEE/SEP): 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
- No injected biasing current in the antennas

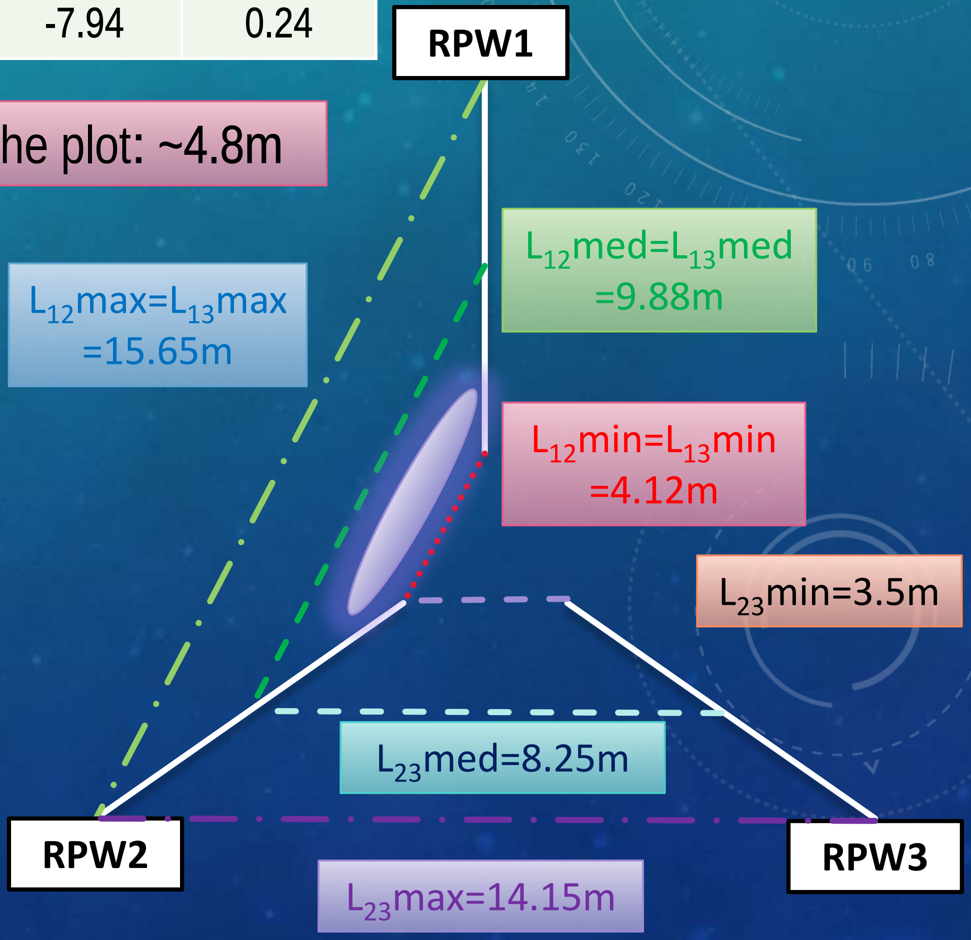
RPW: FIRST ESTIMATIONS OF EFFECTIVE LENGTHS

Case	*B (T)*	*E (V/m)*	*Ground (V)*	*RPW1 (V)*	*RPW2 (V)*	*RPW3 (V)*	*Phi1-2 (V)*	*Phi1-3 (V)*	*Phi2-3 (V)*
Case A	0	0	4.48	10.39	10.74	10.54	-0.35	-0.15	0.2
Case B	8.00E-07	0.32	9.38	15.39	17.28	17.06	-1.89	-1.67	0.22
Case D	2.50E-06	1	17.79	23.39	28.29	28.09	-4.90	-4.70	0.20
Case C	4.00E-06	1.6	25.15	30.73	38.91	38.67	-8.18	-7.94	0.24

Without SC body and considering only the 3 RPW elements: **Leff ~ 6 m**

Starting from E = - $\Delta\varphi / L_{eff}$: it gives $\Delta\varphi = - L_{eff}.E$, with L_{eff} being the slope of the plot: ~4.8m



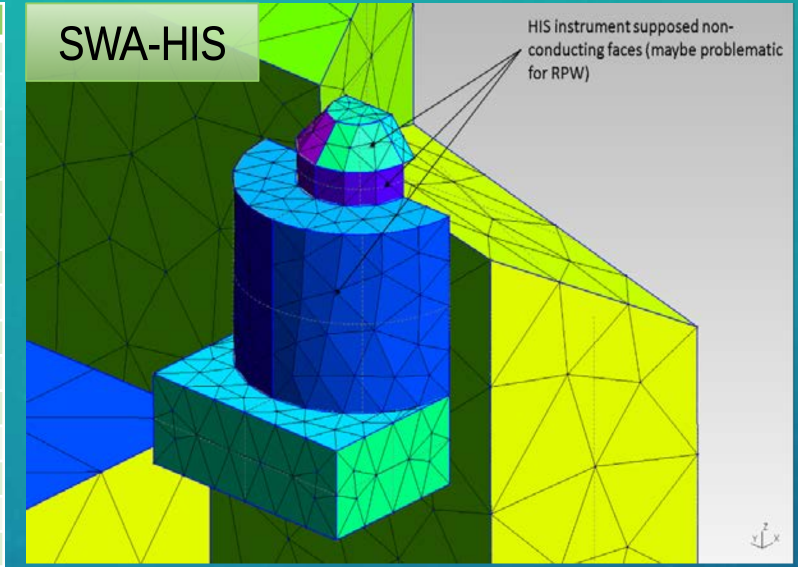


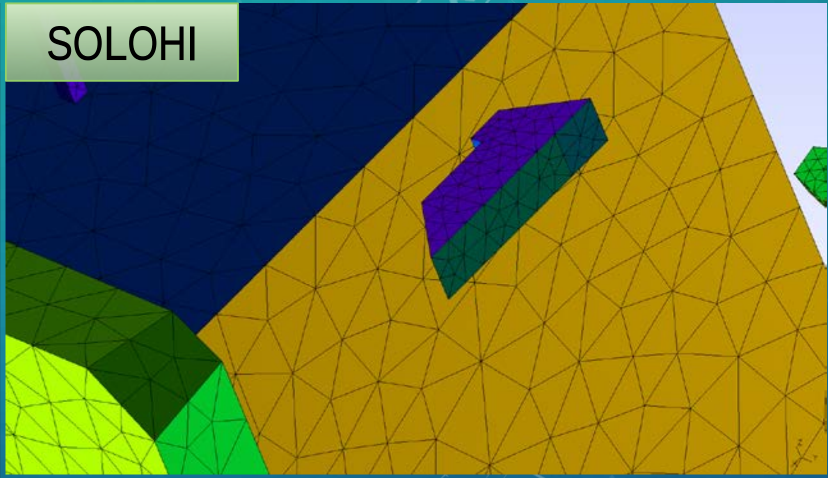
RPW: RECENT SIMULATIONS INCLUDING BIASING CURRENTS

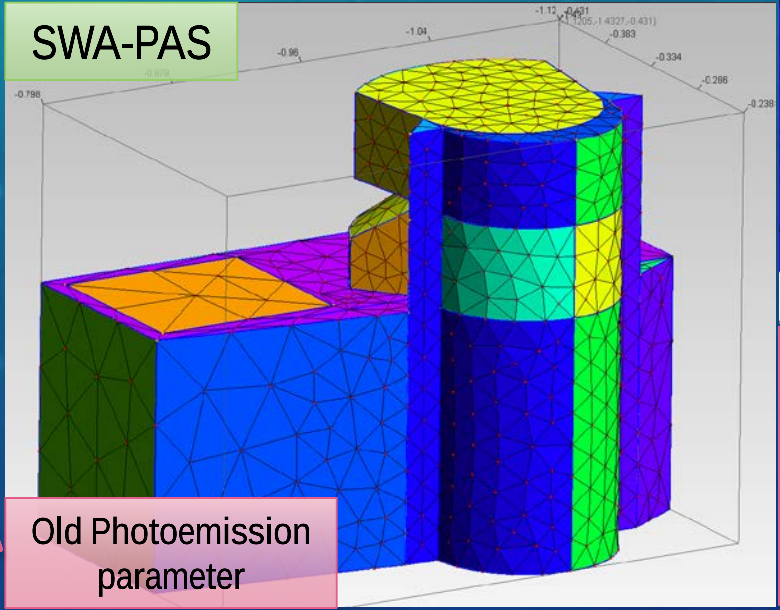
ElecNode	Name	ID	Localization	Material
0	SC BODY	117	“Center”	BK2K
0	SA1 rear	120	"-Y"	CFRP
0	SA2 rear	122	"+Y"	CFRP
0	SA1 side	124	"-Y"	CFRP
0	SA2 side	125	"+Y"	CFRP
0	HGA mast	197	"-Z"	BK2K
0	HGA	198	"-Z"	BK2K
0	BOOM	199	"-X"	CFRP
0	YOKE2 cond	1201	"+Y"	BK2K
0	YOKE1 cond	1203	"-Y"	BK2K
0	RPW1 shield	1702	"+Z"	NIOB
0	RPW2 shield	1706	"-Y"	NIOB
0	RPW3 shield	1710	"+Y"	NIOB
0	SC Shield	14156	"+X"	STEE
0	HIS cond	17072	"+Z"	BK2K
0	SOLOHI cond	18041	"+Y"	BK2K
0	PAS cond	19301	"-Z"	BK2K
0	RPW1 boom	1704	"+Z"	CFRP
0	RPW2 boom	1708	"-Y"	CFRP
0	RPW3 boom	1712	"+Y"	CFRP
1	RPW1	1703	"+Z"	ELGI
2	RPW2	1707	"-Y"	ELGI
3	RPW3	1711	"+Y"	ELGI
4	RPW1 preamp	1701	"+Z"	CFRP
5	RPW2 preamp	1705	"-Y"	CFRP
6	RPW3 preamp	1709	"+Y"	CFRP
7	SA1 front	119	"-Y"	CERS
8	SA2 front	121	"+Y"	CERS
9	YOKE1 diel	1202	"-Y"	OSR2K
10	YOKE2 diel	1200	"+Y"	OSR2K
11	HIS diel	17073	"+Z"	NP2K/BK2K
12	SOLOHI diel	18040	"+Y"	NP2K/BK2K
13	PAS diel	19300	"-Z"	NP2K/BK2K
14	YOKE2 diel in shadow	1204	"+Y"	KAPT/BK2K
15	YOKE1 diel in shadow	1205	"-Y"	KAPT/BK2K

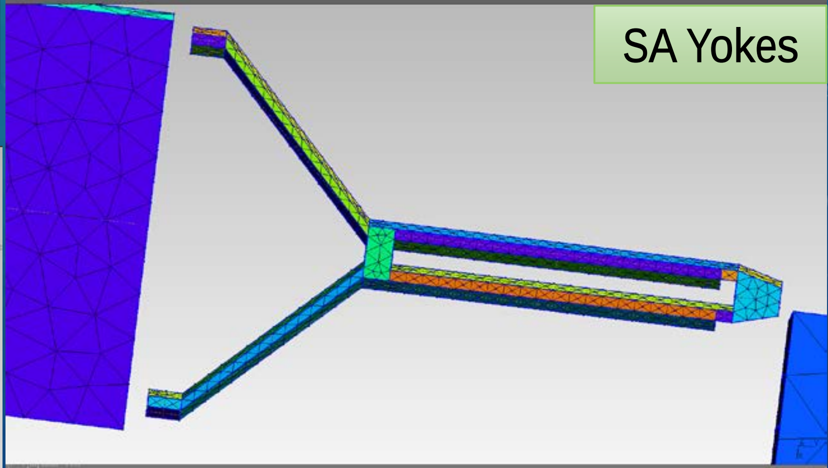
SC materials

Old Photoemission parameter



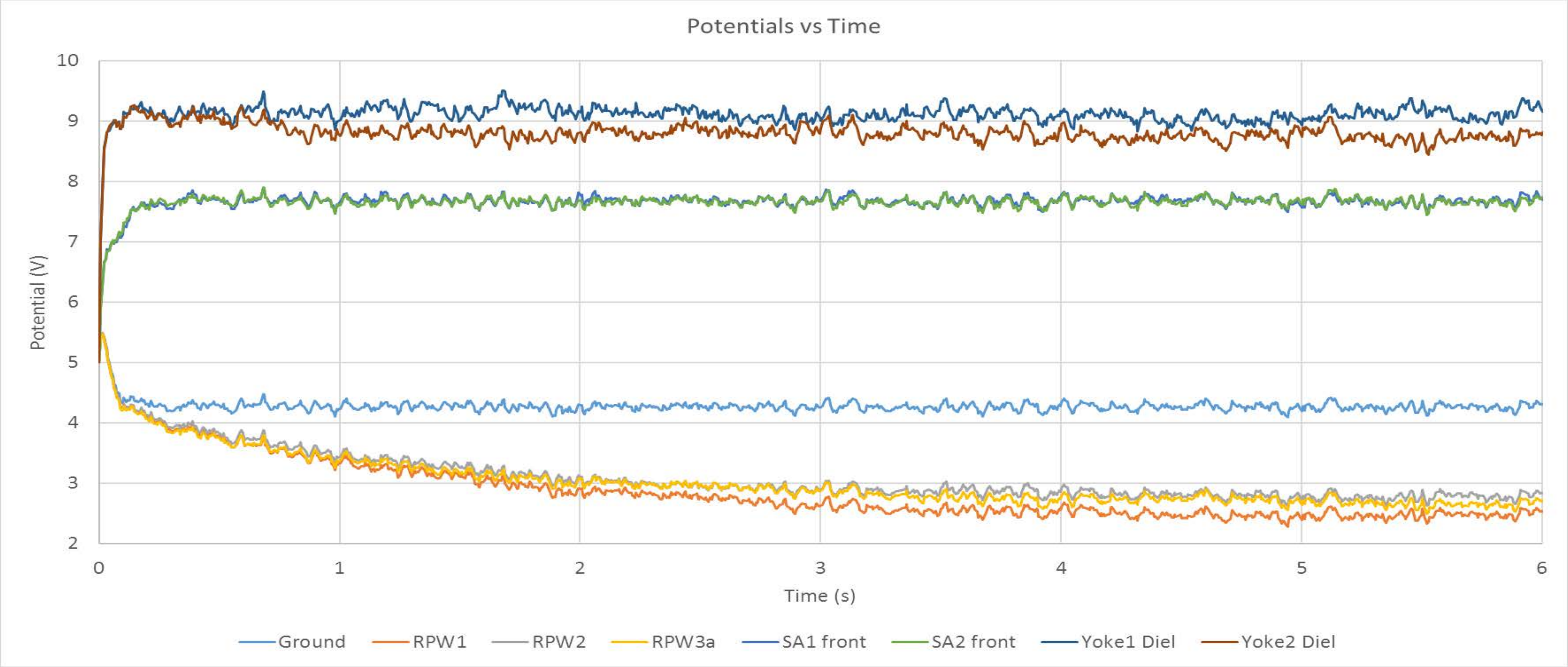






Other simulations with non-conducting parts of instruments and rear SA faces were performed and are detailed in report document

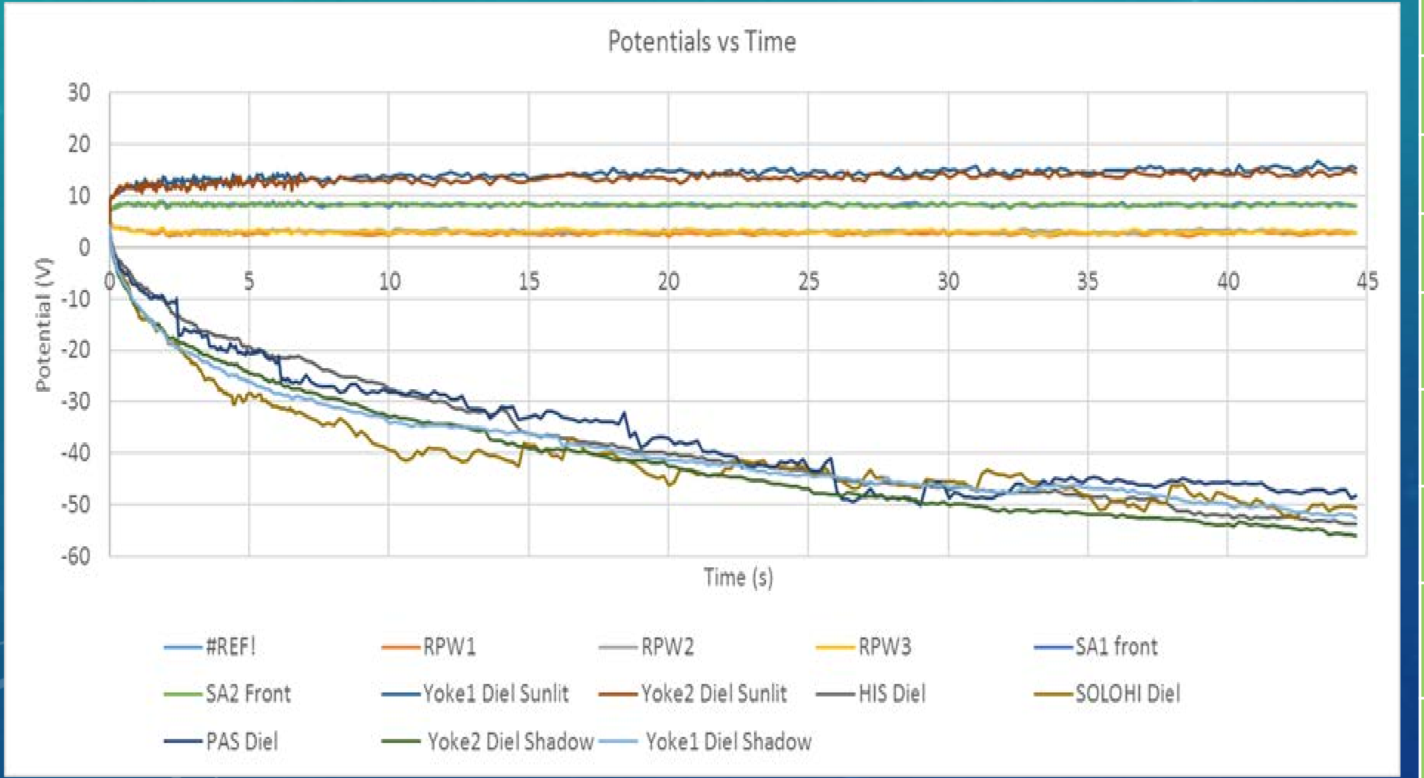
RPW: REF CASE: NO B, NO I_BIAS, NO DIELECTRICS IN SHADOW



	Ground	RPW1	RPW2	RPW3	SA1 front	SA2 front	Yoke1 Diel	Yoke2 Diel
Φ (V)	4.264	2.492	2.812	2.712	7.678	7.667	9.094	8.748
σ (V)	0.060	0.069	0.072	0.074	0.067	0.071	0.104	0.099
ΔΦ (V)	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002

RPW: WORST CASE: NO B, NO IBIAS, BUT WITH DIELECTRICS IN SHADOW

ElecNode	Name	ID	Localization	Material
7	SA1 front	119	"-Y"	CERS
8	SA2 front	121	"+Y"	CERS
9	YOKE1 diel	1202	"-Y"	OSR2K
10	YOKE2 diel	1200	"+Y"	OSR2K
11	HIS diel	17073	"+Z"	NP2K/BK2K
12	SOLOHI diel	18040	"+Y"	NP2K/BK2K
13	PAS diel	19300	"-Z"	NP2K/BK2K
14	YOKE2 diel in shadow	1204	"+Y"	KAPT/BK2K
15	YOKE1 diel in shadow	1205	"-Y"	KAPT/BK2K

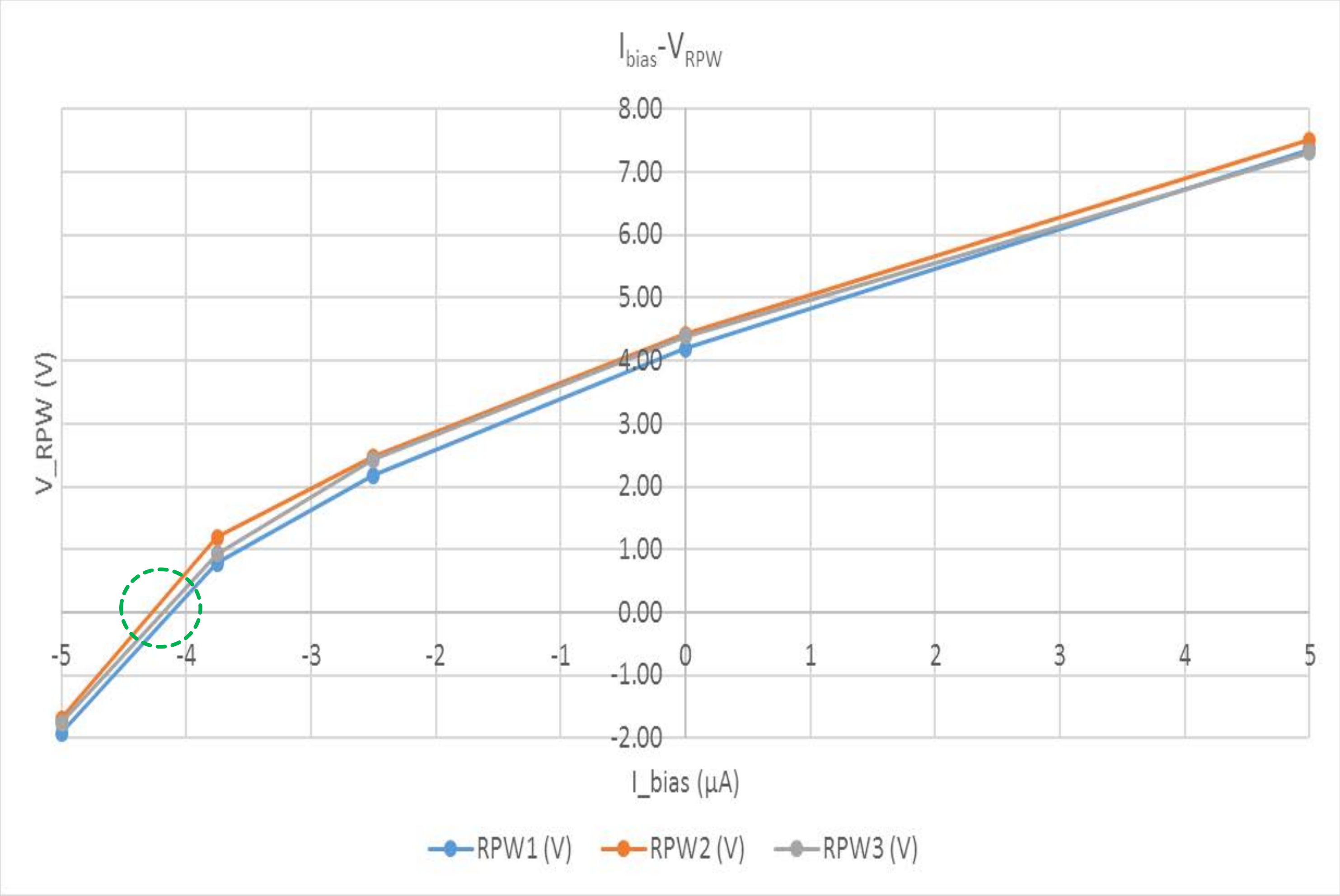


SC Element \ Value	REF Φ (V)	σ (V)	ΔΦ (V)	Worst Φ (V)	σ (V)	ΔΦ (V)	Diff Worst#REF (%)
Ground	4.26	0.060	0.001	4.18	0.131	0.009	2.1
RPW1	2.49	0.069	0.002	2.72	0.222	0.015	9.3
RPW2	2.81	0.072	0.002	3.13	0.244	0.016	11.6
RPW3	2.71	0.074	0.002	2.98	0.209	0.014	10.2
SA1 front	7.67	0.067	0.002	8.30	0.204	0.014	8.1
SA2 front	7.66	0.071	0.002	8.22	0.180	0.012	7.3
Yoke1 Diel Sun	9.09	0.104	0.002	15.1	0.512	0.034	66.4
Yoke2 Diel Sun	8.74	0.099	0.002	14.20	0.435	0.029	62.3
HIS Cond/Diel	4.26	0.060	0.001	-51.32	1.779	0.120	1303.7
SOLOHI Cond/Diel	4.26	0.060	0.001	-49.61	1.448	0.098	1263.5
PAS Cond/Diel	4.26	0.060	0.001	-46.25	0.991	0.067	1184.9
Yoke2 Cond/Diel Shadow	4.26	0.060	0.001	-53.59	1.201	0.081	1357.0
Yoke1 Cond/Diel Shadow	4.26	0.060	0.001	-49.60	1.759	0.118	1263.3

RPW: OTHER CASES: B, NO DIELEC IN SHADOW, MAKING I_BIAIS VARY

Constant magnetic field B of 124.4 nT in the X-Y plane with By= 36.3×10^{-9} T and Bx = -119.7×10^{-9} T (angle of ~17° with the -X direction). This B field generates the expected electric field E: Ez = +7.38 mV/m, fully vertical.

I_biais (µA) *Std Dev (V)*	RPW1 (V)	RPW2 (V)	RPW3 (V)	Ground (V)	SA1 front (V)	SA2 front (V)	Yoke1 Diel (V)	Yoke2 Diel (V)
-5.00 (0.6)	-1.92	-1.68	-1.75	6.85	10.24	10.21	12.31	12.03
-3.75 (0.3)	0.78	1.19	0.93	5.73	9.15	9.14	10.59	10.27
-2.50 (0.3)	2.18	2.47	2.43	5.81	9.22	9.20	10.64	10.31
0.00 (0.4)	4.20	4.42	4.39	5.91	9.32	9.28	10.78	10.46
5.00 (0.3)	7.36	7.51	7.32	6.15	9.25	9.22	10.78	10.37



Plot of the RPW stacer potential evolution as a function of I_bias injected. RPW potential should be null for I_biais ~ -4.25 µA: for this photoemission parameter of ELGILOY (properties changed since…)

RPW: COMPLIANCE TABLE

Requirement Number	Requirement	Descriptive Explanation	**Project Achievements**
Spacecraft Model Requirements			
RPW-SPIS-0010	The project shall provide a spacecraft model suitable for use in the SPIS toolkit and which appropriately supports the needs to assess the satellite perturbations on the RPW DC/LF satellite potential measurements.		Done. Spacecraft model provided to LESIA and ESA.
RPW-SPIS-0020	The model shall include all spacecraft surfaces which will provide, or potentially may provide, a significant perturbation of RPW DC measurements.	HGA, Solar panels	Done. All concerned surfaces included in the model provided to LESIA and ESA.
RPW-SPIS-0030	The model shall be updated to include any significant design modifications communicated to the modelling team during the contract.		Done. Model frequently updated during the project. Latest relevant model provided. Elgilloy material requires updated data on photoemission properties (ONERA).
RPW-SPIS-0040	The model geometry shall be parameterized to include flexibility to model potentially relevant future changes.	Further changes may be required if, for example, the Prime introduces a series of baffles to the spacecraft design in order to address presently unresolved contamination issues.	Done. Provided model is entirely Modularized and parameterized with corresponding descriptions included in all geo files.
RPW-SPIS-0050	The spacecraft model shall provide the ability to assess the effect of movable sub-units (e.g. the HGA and the Solar Arrays) on the measurements of RPW.	It is anticipated that the orientation of these surfaces will continue to vary during the mission.	Done. Parameters allowing HGA and Solar Arrays rotations are available in the geo files.

RPW: COMPLIANCE TABLE

Requirement Number	Requirement	Descriptive Explanation	**Project Achievements**
	RPW modelling Requirements		
RPW -SPIS-0060	An adequate SPIS model of the RPW antennas need to be constructed so that a representative assessment of the impact of the spacecraft environment on the RWP measurements can be made.	May need to discuss the level of detail that needs to be included to achieve the representative results?	Done. Model discussed and configured with an optimum compromise between geo detail levels and numerical performances.
RPW -SPIS-0070	The modelling work shall provide the (I_{bias}, Φ) curves for a typical RPW antenna, in the case of no external electric field imposed in the simulation box and no spacecraft body.	I_{bias} is the typical biasing current which will be applied by RPW during its operations. I_{bias} = 0 corresponds to floating antenna (BIAS off). The outcome will constitute the undisturbed (I_{bias}, Φ) curves.	**Descoped**. RPW simulations without SC body completely change antennas charging levels and numerical stability. Stacer materials were also outdated. Results would have been totally unrealistic and irrelevant for this study.
RPW -SPIS-0080	The modelling work shall provide the (I_{bias}, Φ_i) curves for all three RPW antennas mounted on the actual Solar Orbiter spacecraft body.	I_{bias} is the typical biasing current which will be applied by RPW during its operations. The outcome will be compared to the undisturbed curves.	Done and presented in this report for the typical Solar Orbiter perihelion environment.
RPW -SPIS-090	The modelling work shall provide the 3D spatial distributions of the photoelectron density and electrostatic potential around the actual Solar Orbiter spacecraft body and the three RPW antennas and antennas boom.		Done. Some results of particle distributions and potential around RPW presented here. Other data available within the simulation packages provided.

RPW: COMPLIANCE TABLE

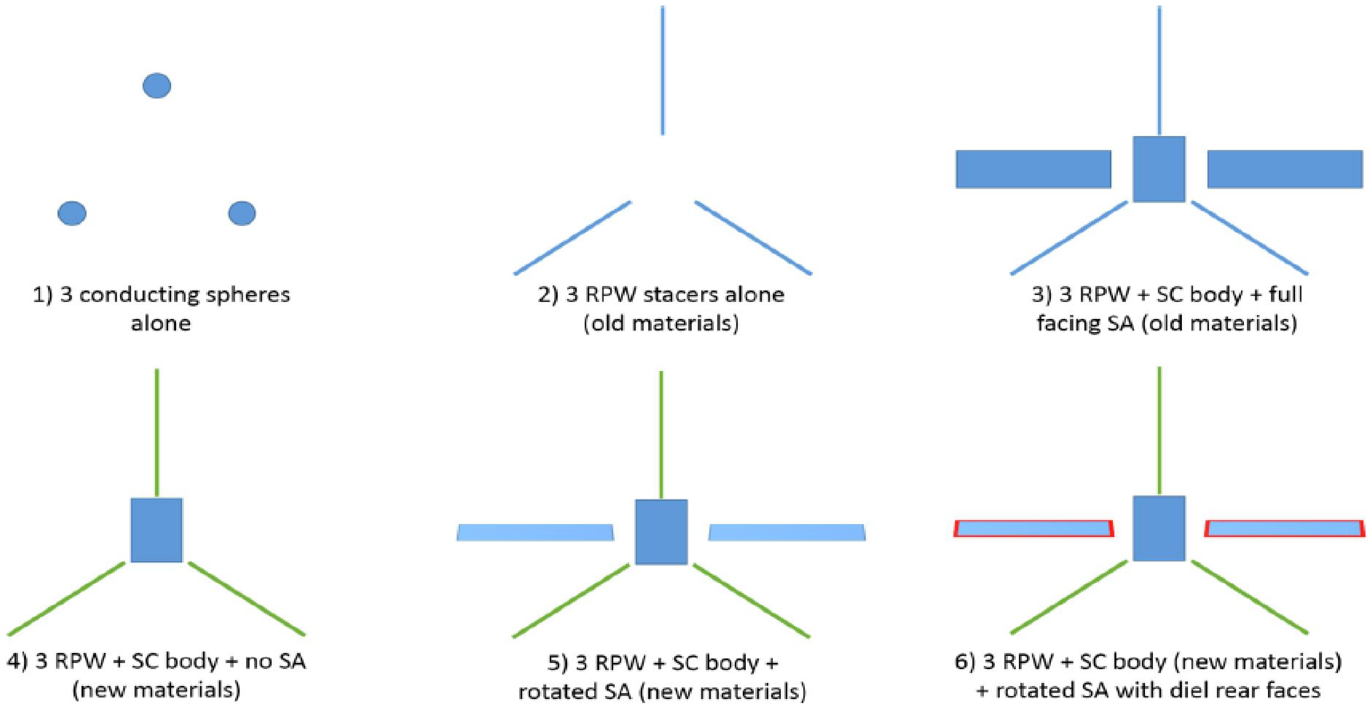
Requirement Number	Requirement	Descriptive Explanation	**Project Achievements**
RPW-SPIS-0100	The modelling work shall provide the $(\delta\Phi_{i12,13}, I_{bias})$ curves for all three RPW antenna, in the case of an external electric field imposed in the simulation box.	These (I_{bias}, Φ_i) curves shall allow determining the effective lengths vectors $\mathbf{L}_{\mathbf{effij}}^*$ modified by the spacecraft electrostatic environment.	Done and presented in this report for the typical Solar Orbiter perihelion environment. But stronger E fields missing and necessary to determine more precisely L_{eff} for latest model
RPW-SPIS-0110	The modelling work shall allow to evaluate the effects on the RPW DC/LF measurements of the S/C body, high gain antenna & solar panels if the RPW antennas are tilted by 30° in the anti-sunward direction		Descoped by ESA.
Model Run Requirements			
RPW-SPIS-0120	The models and their runs shall be saved in a commonly agreed format and presented in a commonly agreed way so that they can be re-used by the RPW instrument team at LESIA laboratory (France) and by the RPW science consortium.		Done. Models and runs saved, provided and presented to LESIA. Simulations already running on LESIA computers.
RPW-SPIS-0130	The RPW instrument team in LESIA shall have the complete set of model runs which would allow continued analysis of the spacecraft environment and its effect on the RPW measurements throughout the post-launch period.	This is to allow the RPW instrument team to assess the effect of any unanticipated environment and/or evolution of the properties of problem surfaces throughout the mission.	Done. Model runs provided to LESIA, ready to be updated for other analysis. Examples of new environment configurations also provided (Kappa distributions).

RPW: CONCLUSION

- This study provided answers to many questions raised from the RPW experiment
- Adequate Solar Orbiter model including the desired RPW system and other modular elements (HGA, solar arrays, yokes, HIS, PAS, SOLOHI instruments) was conceived and updated all along the project
- This model is fully parametrized and easily modifiable, even though it is for now updated with latest information available concerning materials and dimensions of the satellite
- New materials have been generated for SPIS to simulate the Elgiloy and Niobium surfaces. Note that Elgiloy requires updated data on its photoemission properties (ONERA) but they were not available by the end of this project phase (**now available**)
- Effective lengths estimation studies were performed, but without spacecraft elements such as solar array yokes or SWA and SoloHI instruments and out-dated ELGILOY prorperties. The latest spacecraft model however provided the I-V curves for antennas in a typical perihelion environment at 0.28 AU from the Sun
- As requested: all required and necessary models and datasets were provided to LESIA in order to continue this analysis throughout the pre- and post-launch period. LESIA team is now autonomous and trained on this subject
    - New simulations for L_{eff} estimations will be performed at LESIA including new material parameters and latest models of instruments
    - I-V curves will also be redrawn considering new ELGILOY properties
    - Kappa distributions for electrons

Conclusions for the RPW Science performance report

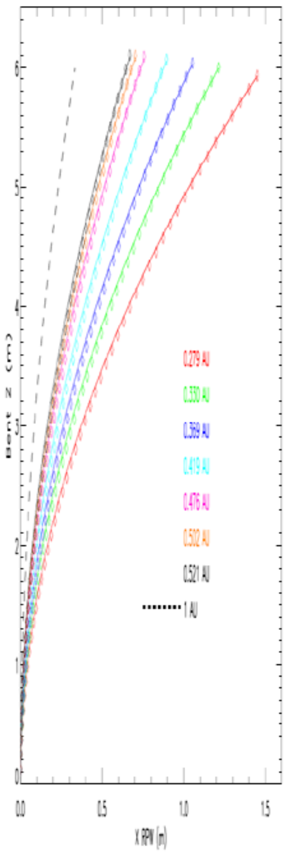
- A final document has been delivered by Stanislas Guillemant (RPW-EAS-SYS-TN-001760-LES-MSSL_iss2rev1).
- It shall be used for the RPW performance report (table page 47)
- LESIA will run a new simulation in configuration 5 with an electric field in the 2-3 direction in order to retrieve the correct Leff2-3
- LESIA will set a depository website will all the SPIS/RPW simulations setups & CAD models
- The correct value of the Elgiloy photoemission properties compared to the Gold one shall be clarified. And in particular the ratio between gold & elgiloy in SPIS and in the ONERA simulations shall be the same

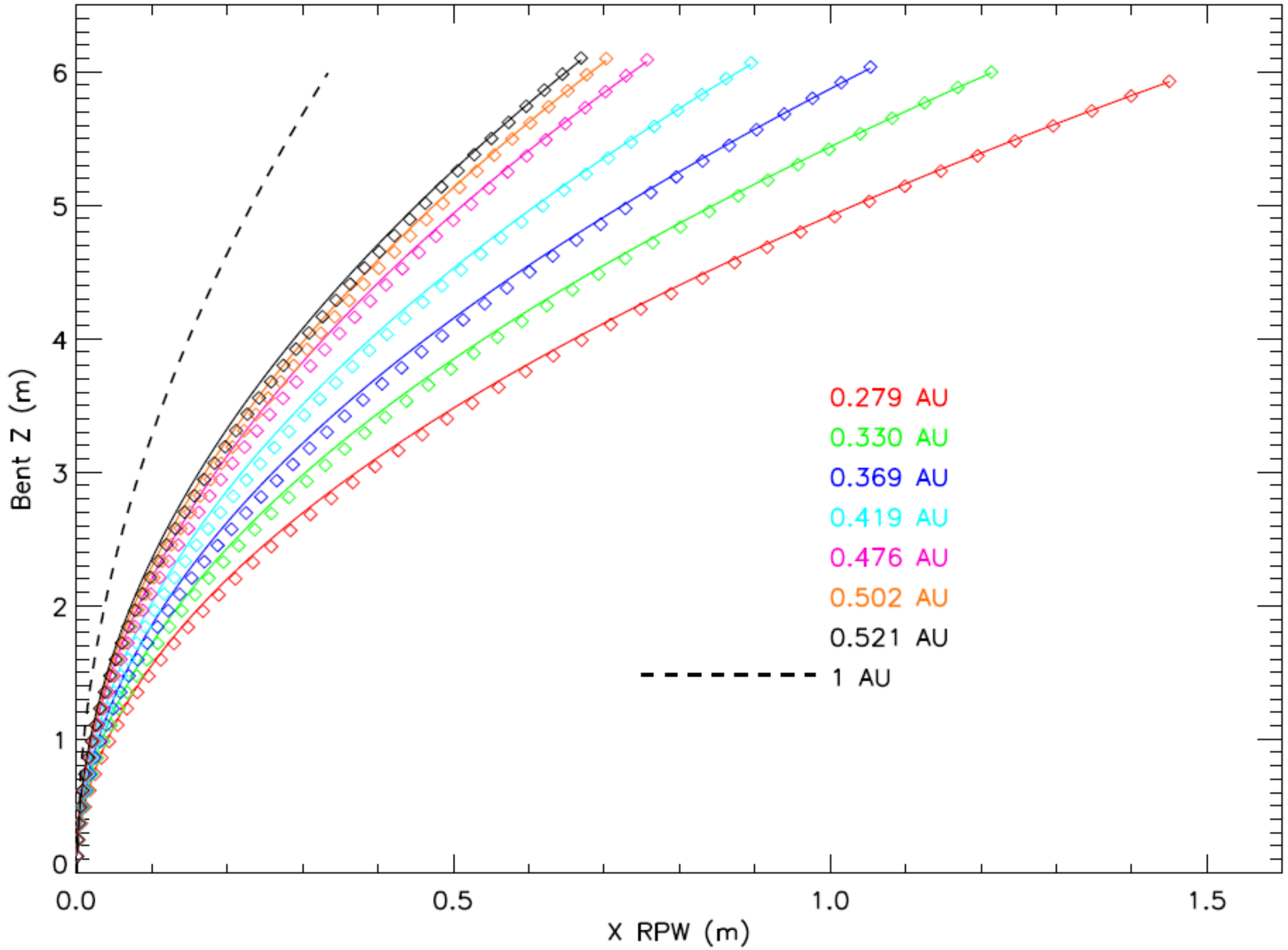


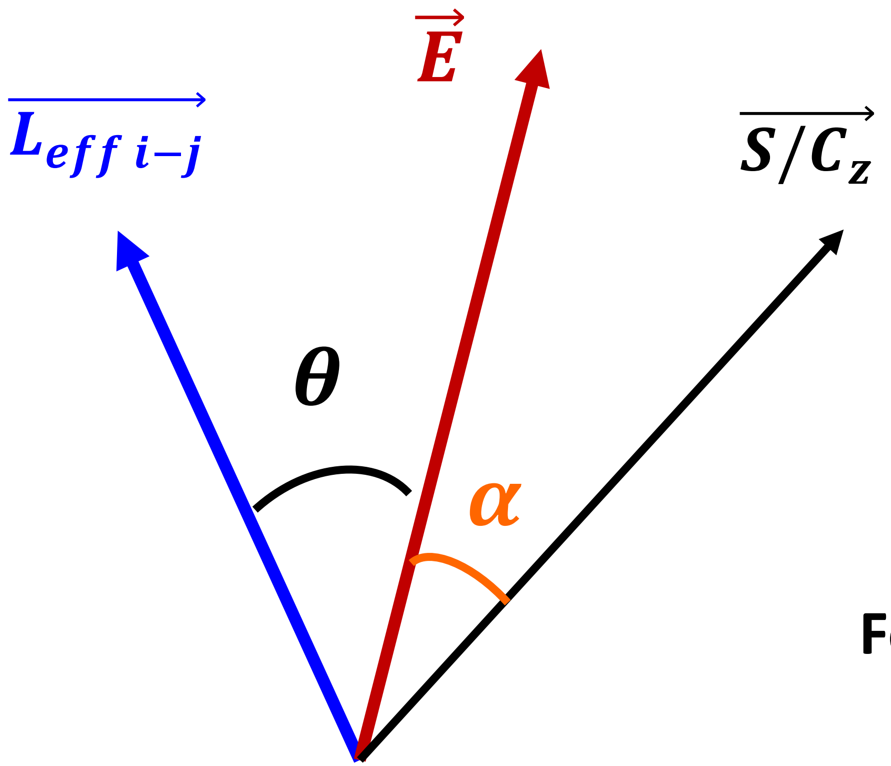
Configuration	1	2	3	4	5	6
ΦRPW1 (V)	13.15	Range	Range	5.04	3.58	1.69
ΦRPW2 (V)	15.93	Range	Range	7.53	6.37	1.82
ΦRPW3 (V)	22.35	Range	Range	8.81	6.69	4.01
Leff 1-2 (m)	**6.80**	**5.83**	**4.83**	**6.28**	**7.05**	**0.33**
Leff 1-3 (m)	**6.80**	**5.83**	**4.83**	**9.51**	**7.86**	**5.88**
Leff 2-3 (m)	**6.40**	**0.00**	**0.00**	***3.23***	**0.82**	**5.55**
Lgeo_min 1-2 (m)	7.59	4.12	4.12	4.12	4.12	4.12
Lgeo_max 1-2 (m)	7.59	15.65	15.65	15.65	15.65	15.65
Lgeo_min 2-3 (m)	7.01	3.50	3.50	3.50	3.50	3.50
Lgeo_max 2-3 (m)	7.01	14.15	14.15	14.15	14.15	14.15

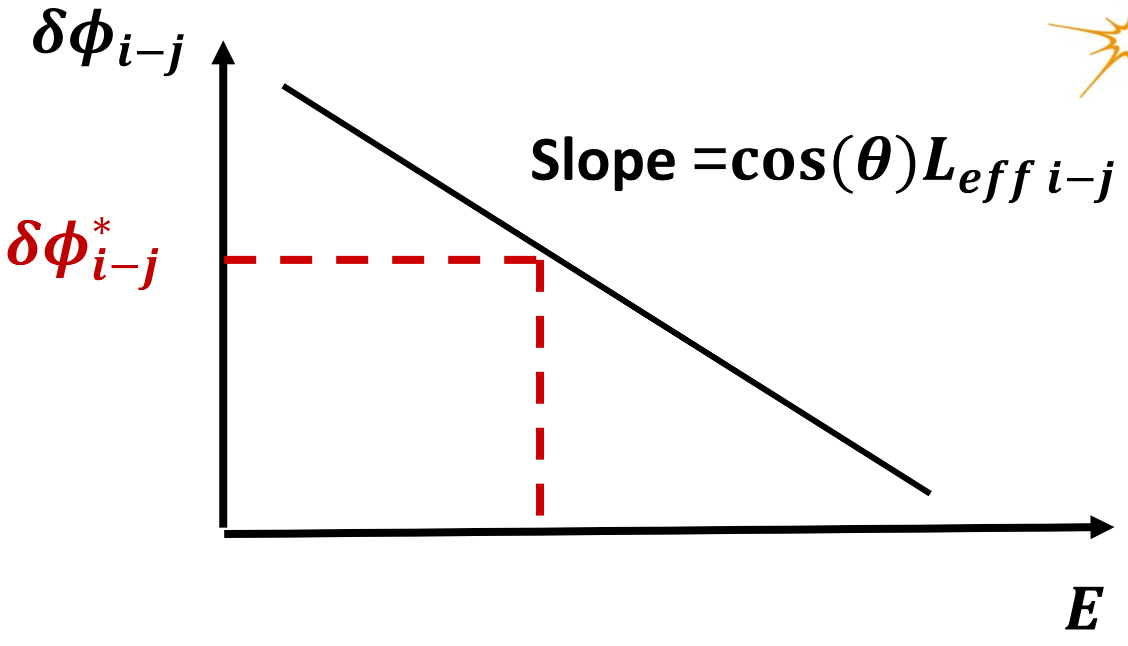
Further RPW/SPIS simulations

- ❑ Effect of the non-thermal electrons (halo & strahl)
- ❑ Effect of the bending geometry

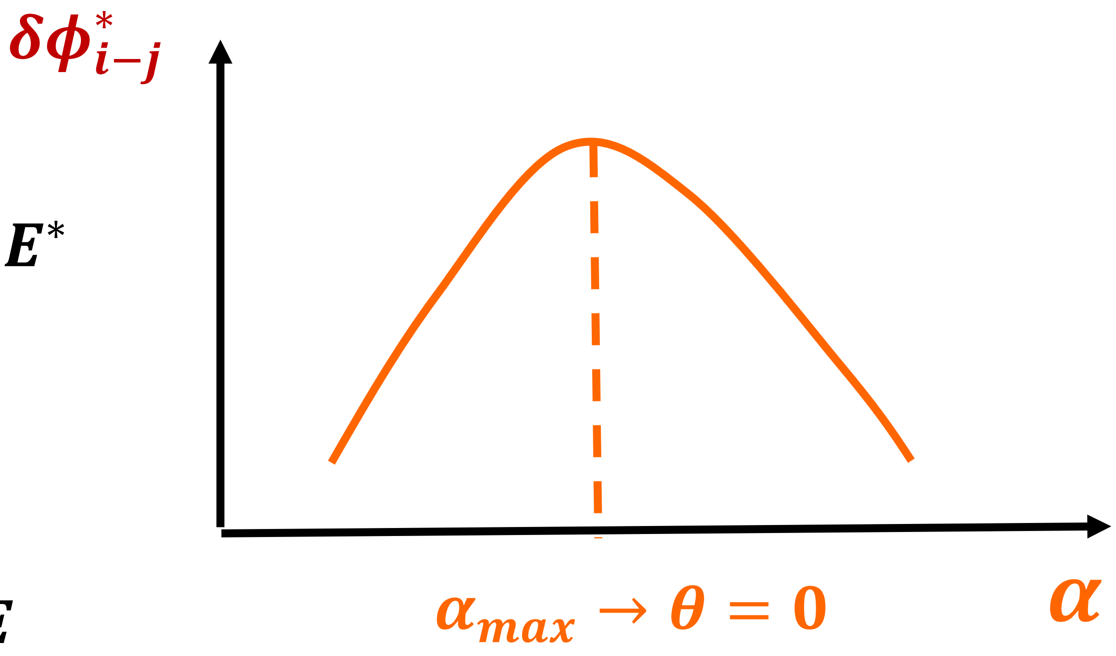








For a given E^*



$$\delta\varphi_{i-j} = \overrightarrow{L_{eff\ i-j}} \cdot \vec{E} = \cos(\theta)L_{eff\ i-j}E$$