# Assessment of Interaction between Spacecrat and EP Systems

**18th SPINE meeting, March 7th 2012, ESTEC**

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# People involved in AISEPS

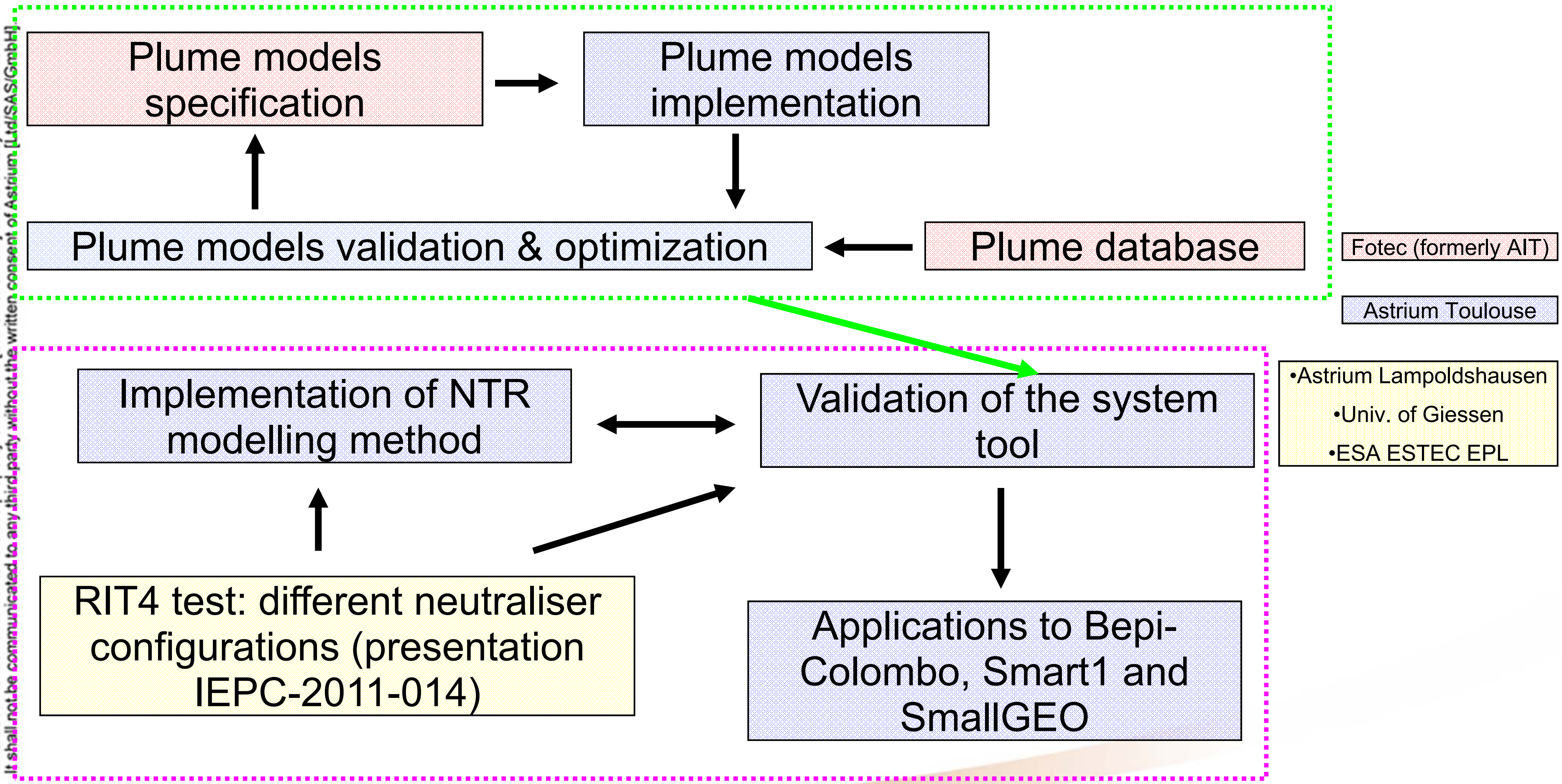
- Astrium Satellites (Toulouse): M. Wartelski, C. Theroude
- FOTEC (formerly AIT): A. Reissner, M. Tajmar
- Astrium ST Lampoldshausen: H. Leiter
- Giessen Univ: B. Lotz & D. Feili
- ESA EPL: J. Perez-Luna, A. Bullit
- ESA Technical Officer: E. Gengembre
- New (CCN): ONERA, P. Sarrailh

# Main goals

- Implement plume models (SPT100, PPS1350, PPS5000, RIT4, RIT10, RIT22, HEMP, T5, T6, InFEEP, CsFEEP) in SPIS in order to simulate the plasma environment generated by EP around spacecraft and validate them

- Perform system simulations taking into account the EP grounding configuration (floating, grounded, resistor…) wrt to main S/c ground:
  - Predict the S/c floating potential during EP firing
  - Help predicting the neutraliser electron current

# Study approach

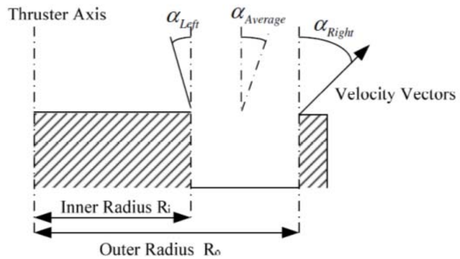



*Before CCN

# Plume Models Philosophy

- Plume injection models widely used (SmartPIC, PICPlus, Astrium…)

- Hybrid-Particle-in-Cell (PIC) method:
  - Ions (fast and CEX) simulated as PIC super-particles
  - Neutrals are simulated with super-particles or analytically
  - Electrons are simulated as a fluid
    - Constant or variable electron temperature $T_e n_e^{1-\gamma}$=cons
  - Plasma potential: Poisson solver or « neutrality »
  - Neutrality:
    - $n_e = n_i$
    - Constant $T_e$: $\Phi_p = T_e.\ln(n_i/n_{ref}) + \Phi_{ref}$
    - Variable $T_e$: $\Phi_p = T_e/(\gamma-1).[(n_i/n_{ref})^\wedge(\gamma-1) -1] + \Phi_{ref}$

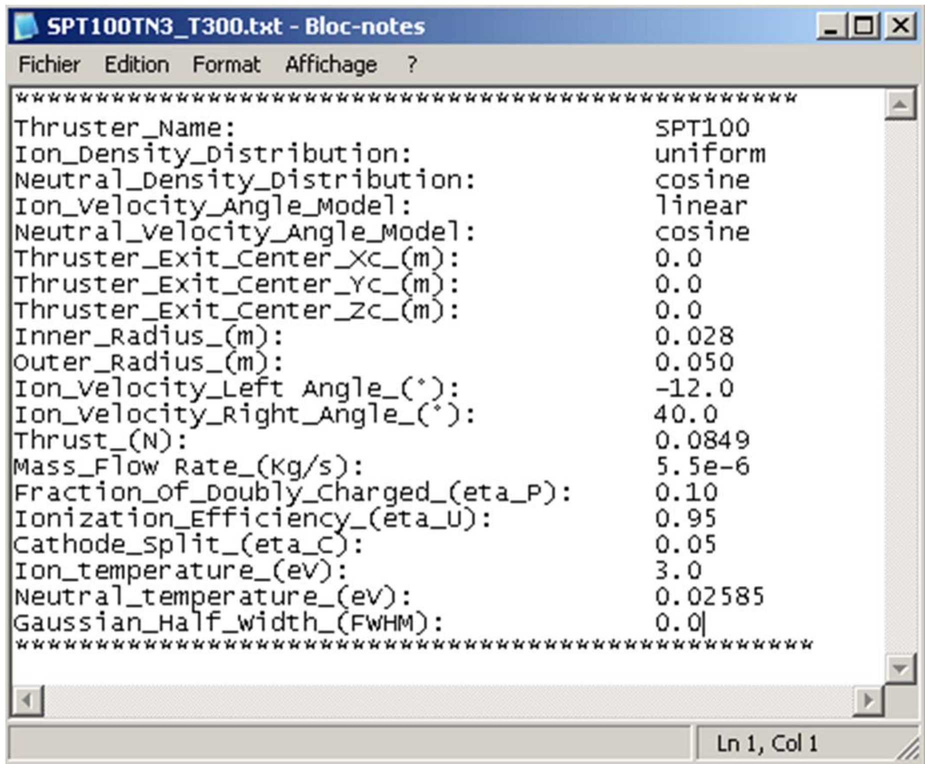



# Plume Models Philosophy

- Fast ions (singly, doubly charged) and neutrals are injected at thruster's exit plane
  - Different density distributions and velocity models over the surface have been implemented and can be selected
- Carge-exchange ions (CEX) are modelled with the Monte-Carlo Collision (MCC) method
  - Fast neutrals produced by a CEX collision are not simulated
  - Elastic collisions are not currently implemented in SPIS (but could be)

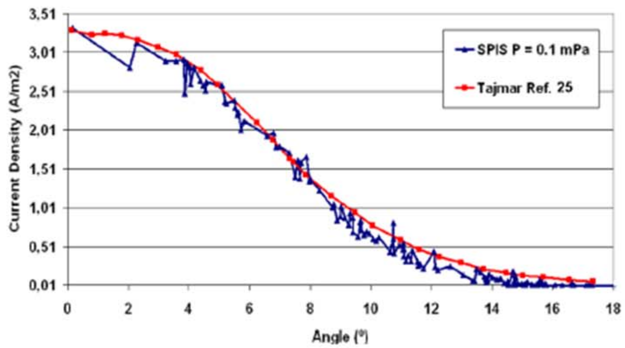
# Easy access to plume models from UI



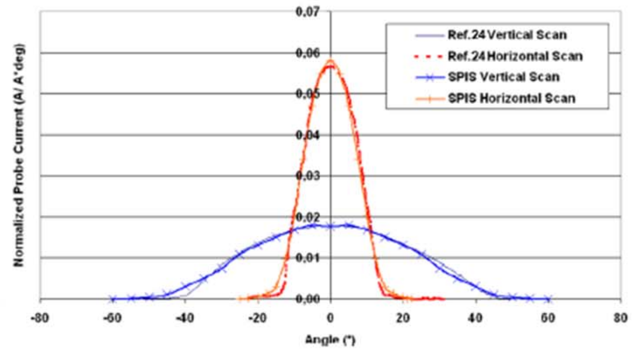



```
************************************************
Thruster_Name:                              SPT100
Ion_Density_Distribution:                   uniform
Neutral_Density_Distribution:               cosine
Ion_Velocity_Angle_Model:                   linear
Neutral_Velocity_Angle_Model:               cosine
Thruster_Exit_Center_Xc_(m):                0.0
Thruster_Exit_Center_Yc_(m):                0.0
Thruster_Exit_Center_Zc_(m):                0.0
Inner_Radius_(m):                           0.028
Outer_Radius_(m):                           0.050
Ion_Velocity_Left Angle_(°):                -12.0
Ion_Velocity_Right_Angle_(°):               40.0
Thrust_(N):                                 0.0849
Mass_Flow Rate_(Kg/s):                      5.5e-6
Fraction_Of_Doubly_Charged_(eta_P):         0.10
Ionization_Efficiency_(eta_U):              0.95
Cathode_Split_(eta_C):                      0.05
Ion_temperature_(eV):                       3.0
Neutral_temperature_(eV):                   0.02585
Gaussian_Half_Width_(FWHM):                 0.0
*************************************************
```

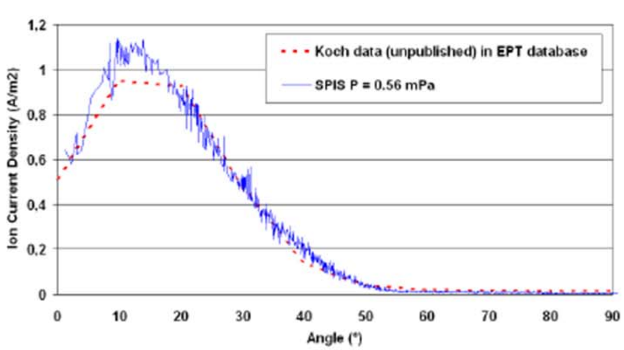
# Plume Models Validation: Plume Axis



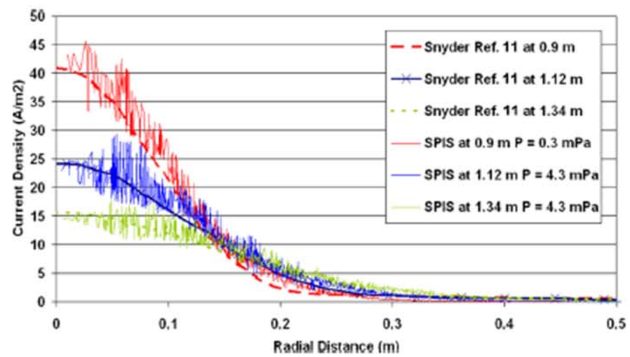

RIT10 ion current density 1.18 m P=$10^{-4}$ Pa



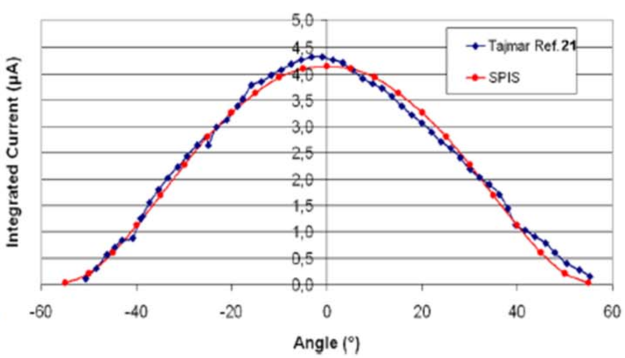

Cesium FEEP ion current



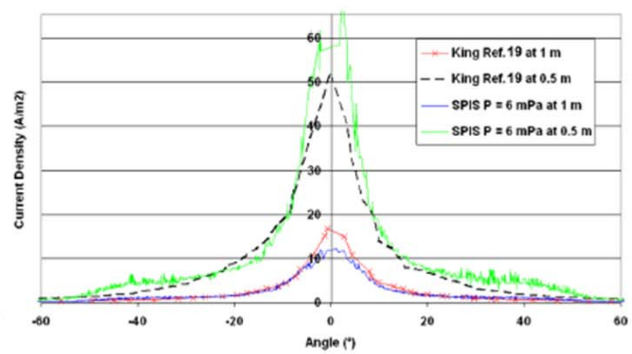

HEMP3050 current density Normalized to 1 A at 1 m




T6 Current Density at different distances




Indium FEEP ion current

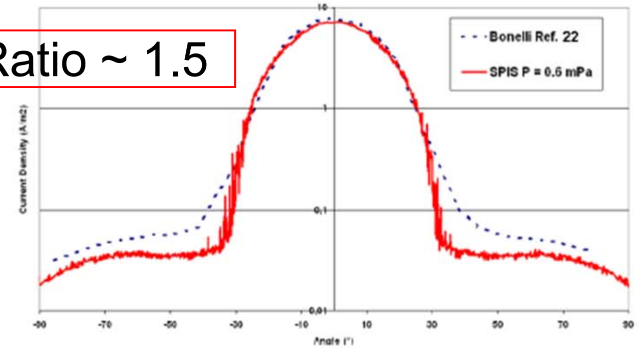



SPT100 current density

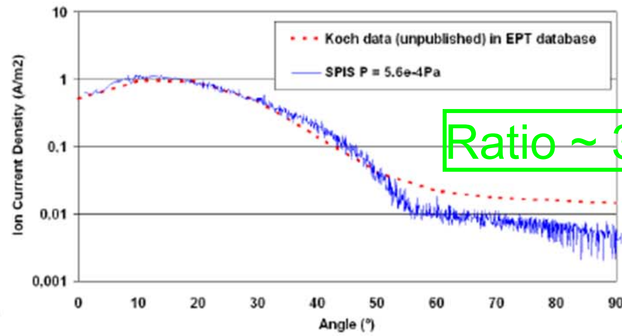
Excellent fit of measured currents in the plume axis for all thrusters!

# Plume Models Validation: High angles

Ratio ~ 1.5

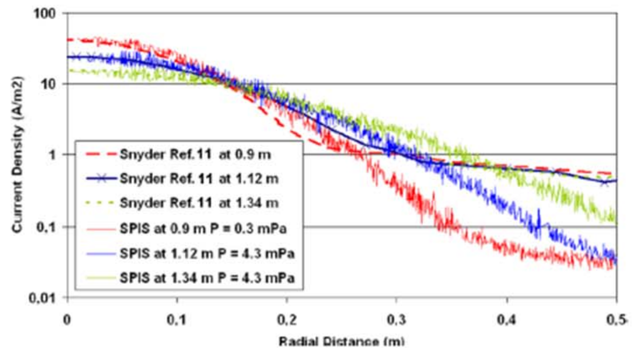



RIT22 current density at 1m

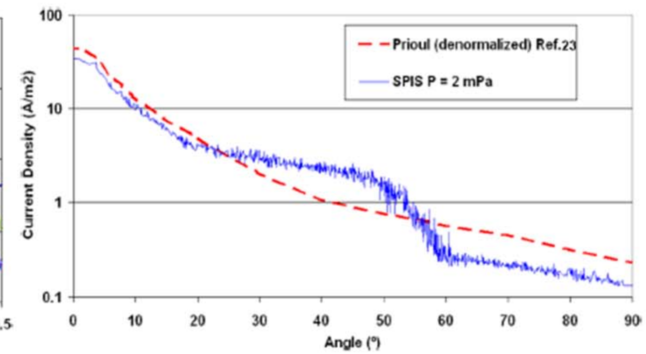



Ratio ~ 3.5

HEMP3050 current density normalized to 1 A at 1 m

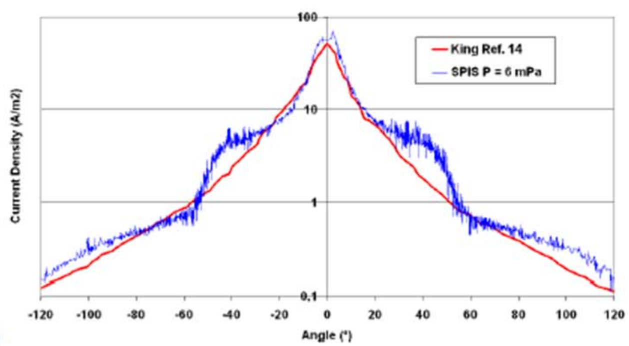



T6 current density at 0.9 m

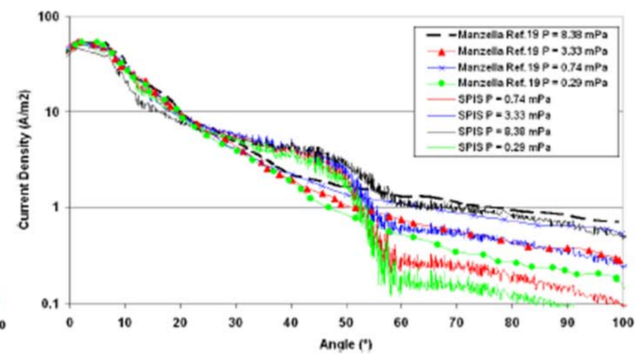



PPS1350 current density at 0.7 m

CEX region: same order of magnitude but slight underestimation wrt on-ground data!



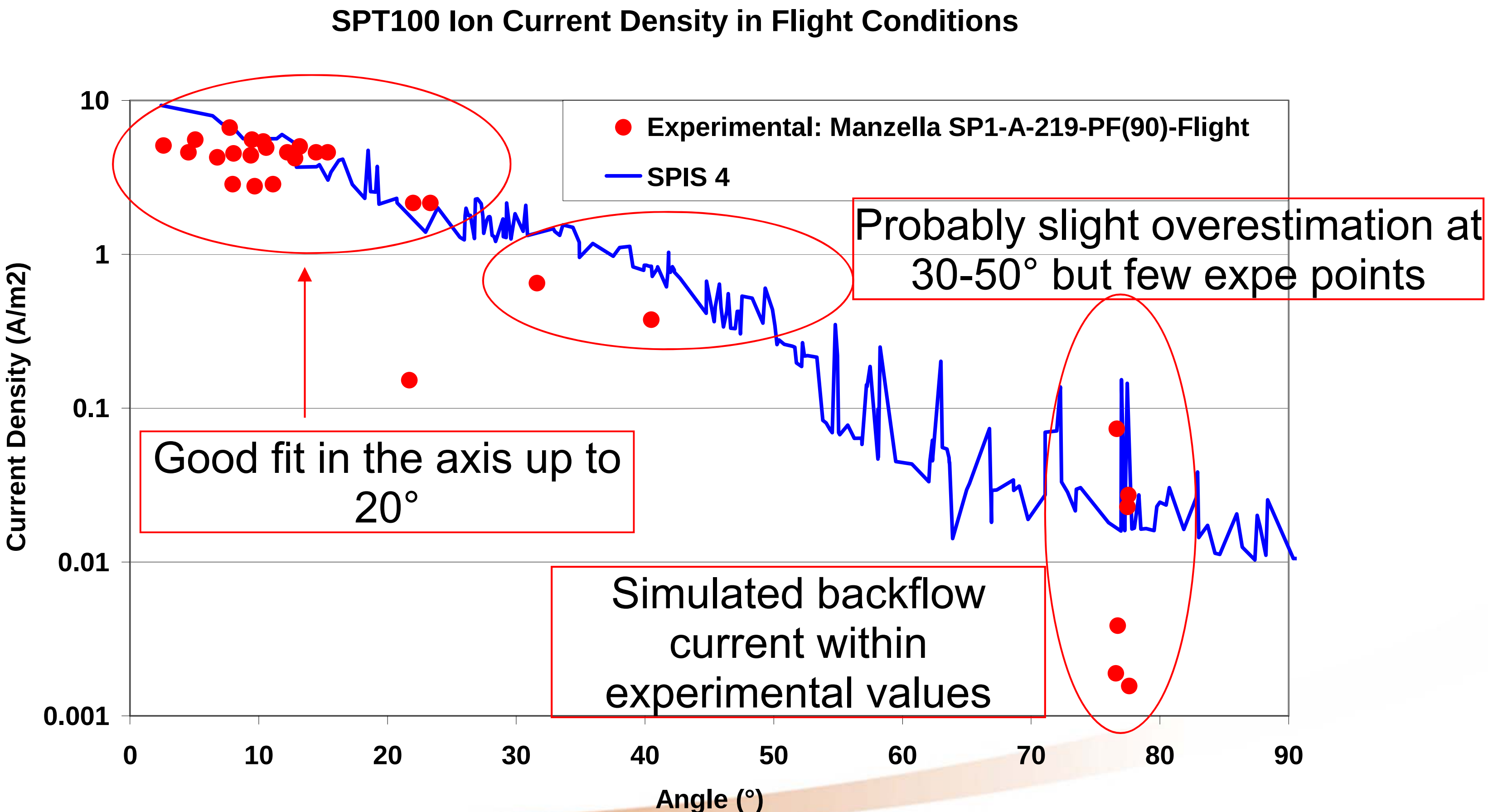

SPT100 current density at 0.5 m compared with King data




SPT100 current density at 0.6 m compared with Manzella data

# SPT100 Current Density: Comparison with Flight Data (Express Satellites)





# System simulations: modelling of interconnectors

- There are hundreds of IC (of millimetric sizes) with potentials biases of 0 to 50 or 100V wrt to Sc ground and distributed between the solar cells
- At system level plasma probably does not « feel » IC potentials due to screening by dielectrics.
- Approach (compatible with « neutrality » only!): « rough » geometrical and electric potential simplification + physical model for electron collection

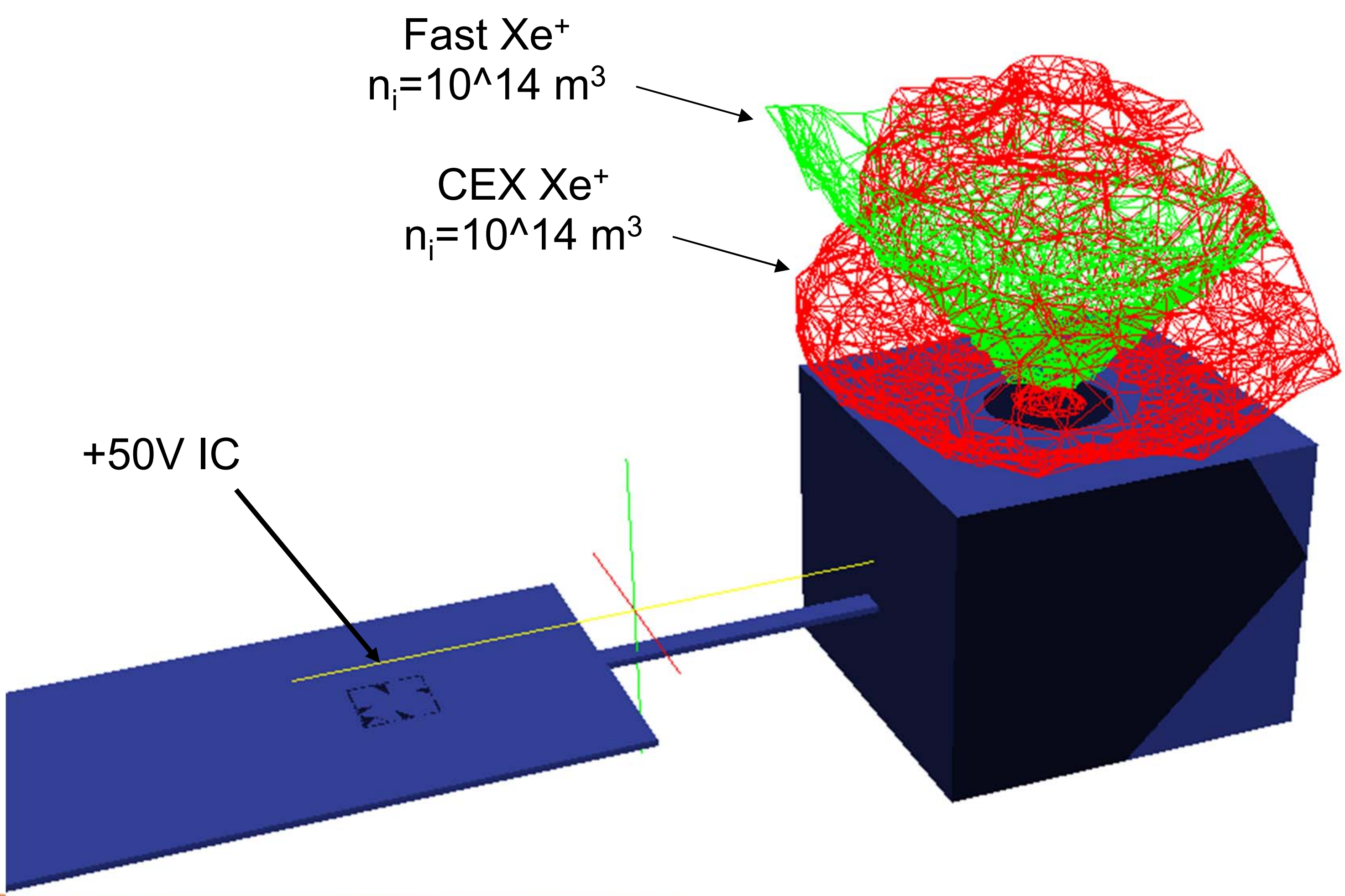
# Modelling of interconnectors

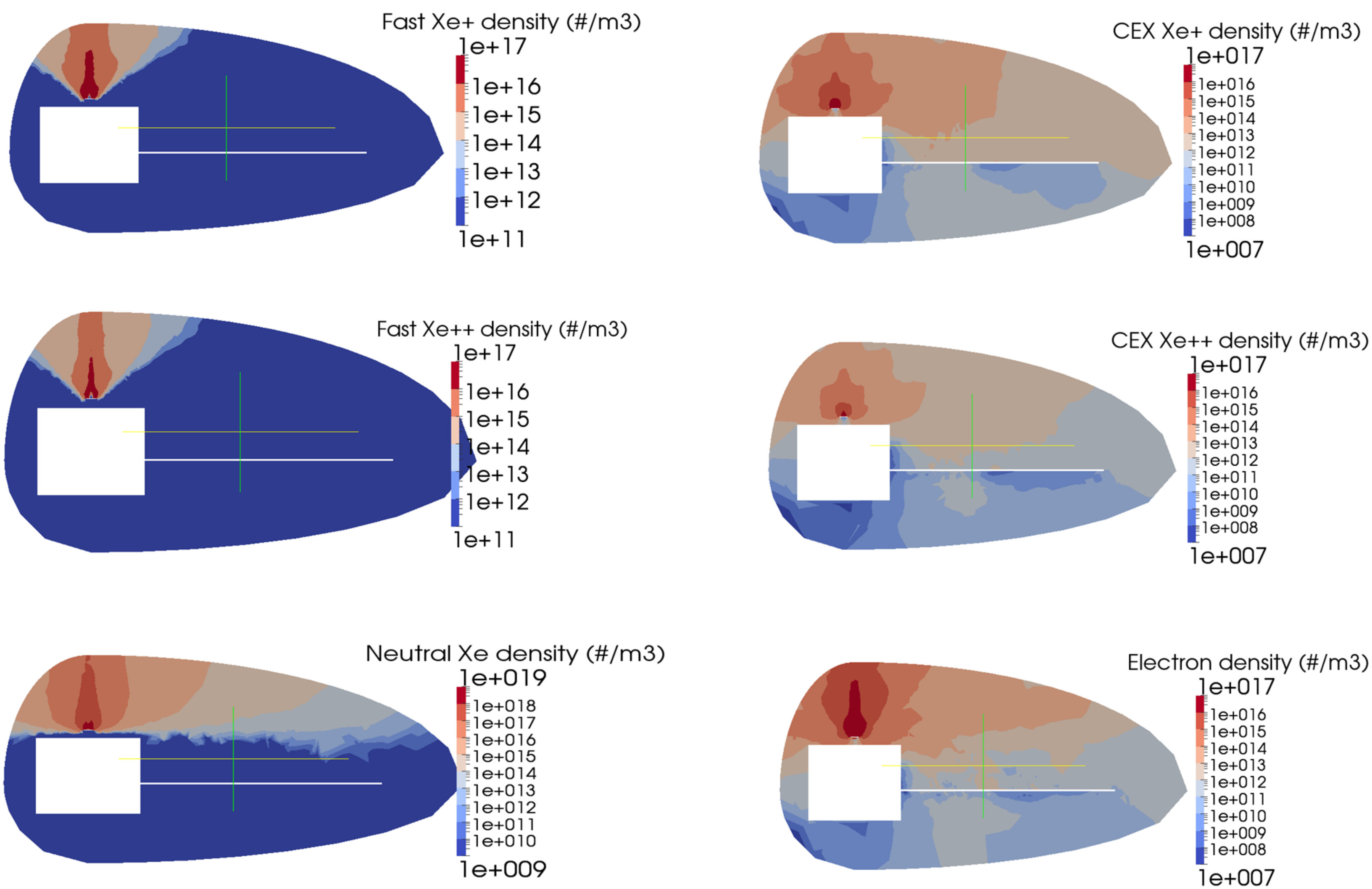
- A modification on the code allows not taking into account the IC potential to calculate the local electric field -> otherwise, CEX ions (E<20eV) would be repelled and no pasma would reach IC

- Neutrality approach (Poisson not solved) does not model the sheathes -> plasma conditions on surfaces correspond to those outside the sheath

- Collected electron current -> OML equations:
  - $V > 0$ $J_e = S.J_{e,th}.(1+eV/kT_e)$
  - $V < 0$ $J_e = S.J_{e,th}.\exp(eV/kT_e)$

# Smart1 simulation

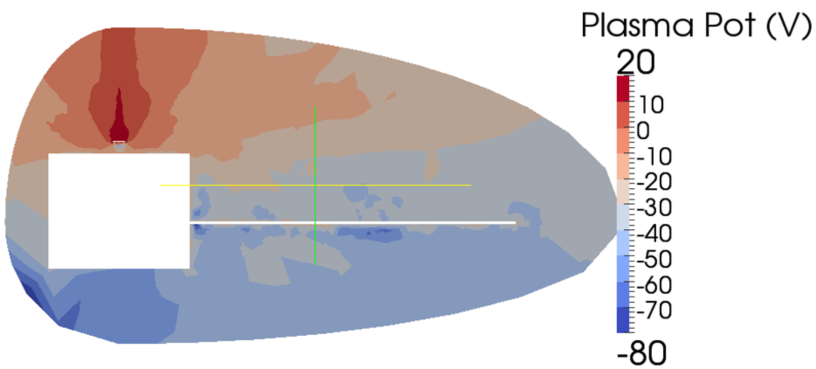


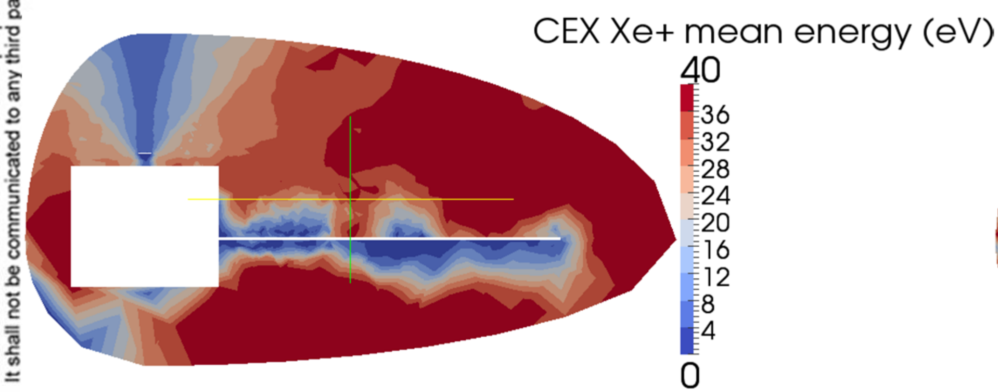

Fast Xe+ density (#/m3)
1e+17
1e+16
1e+15
1e+14
1e+13
1e+12
1e+11
CEX Xe+ density (#/m3)
1e+017
1e+016
1e+015
1e+014
1e+013
1e+012
1e+011
1e+010
1e+009
1e+008
1e+007
Fast Xe++ density (#/m3)
1e+17
1e+16
1e+15
1e+14
1e+13
1e+12
1e+11
CEX Xe++ density (#/m3)
1e+017
1e+016
1e+015
1e+014
1e+013
1e+012
1e+011
1e+010
1e+009
1e+008
1e+007
Neutral Xe density (#/m3)
1e+019
1e+018
1e+017
1e+016
1e+015
1e+014
1e+013
1e+012
1e+011
1e+010
1e+009
Electron density (#/m3)
1e+017
1e+016
1e+015
1e+014
1e+013
1e+012
1e+011
1e+010
1e+009
1e+008
1e+007

# Constant vs variable $T_e$

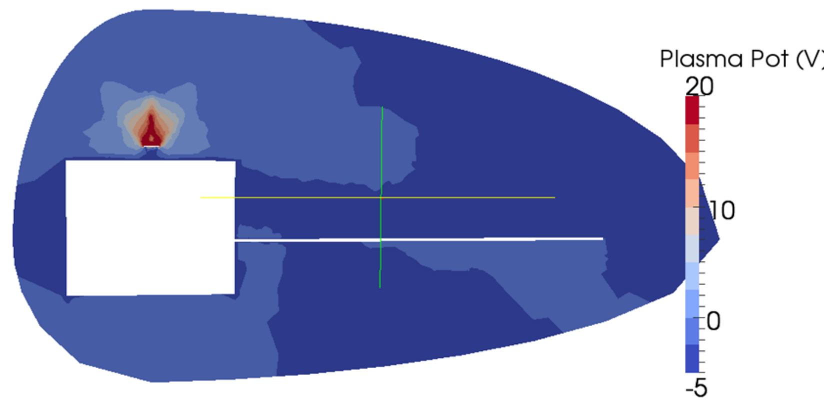


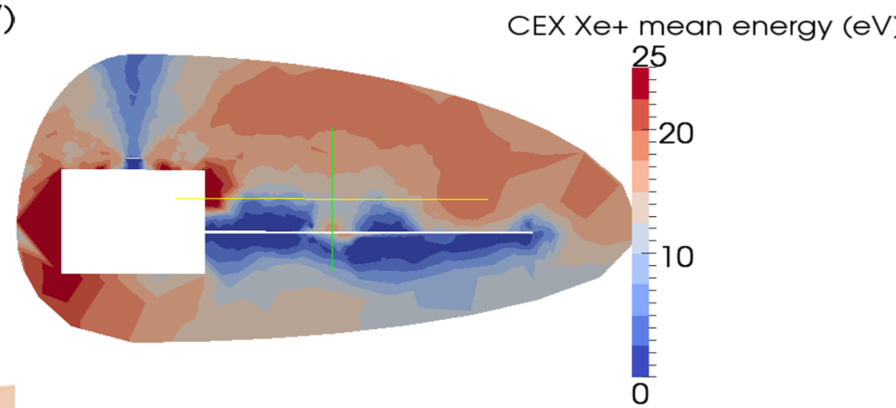
Constant $T_e$ = 4eV



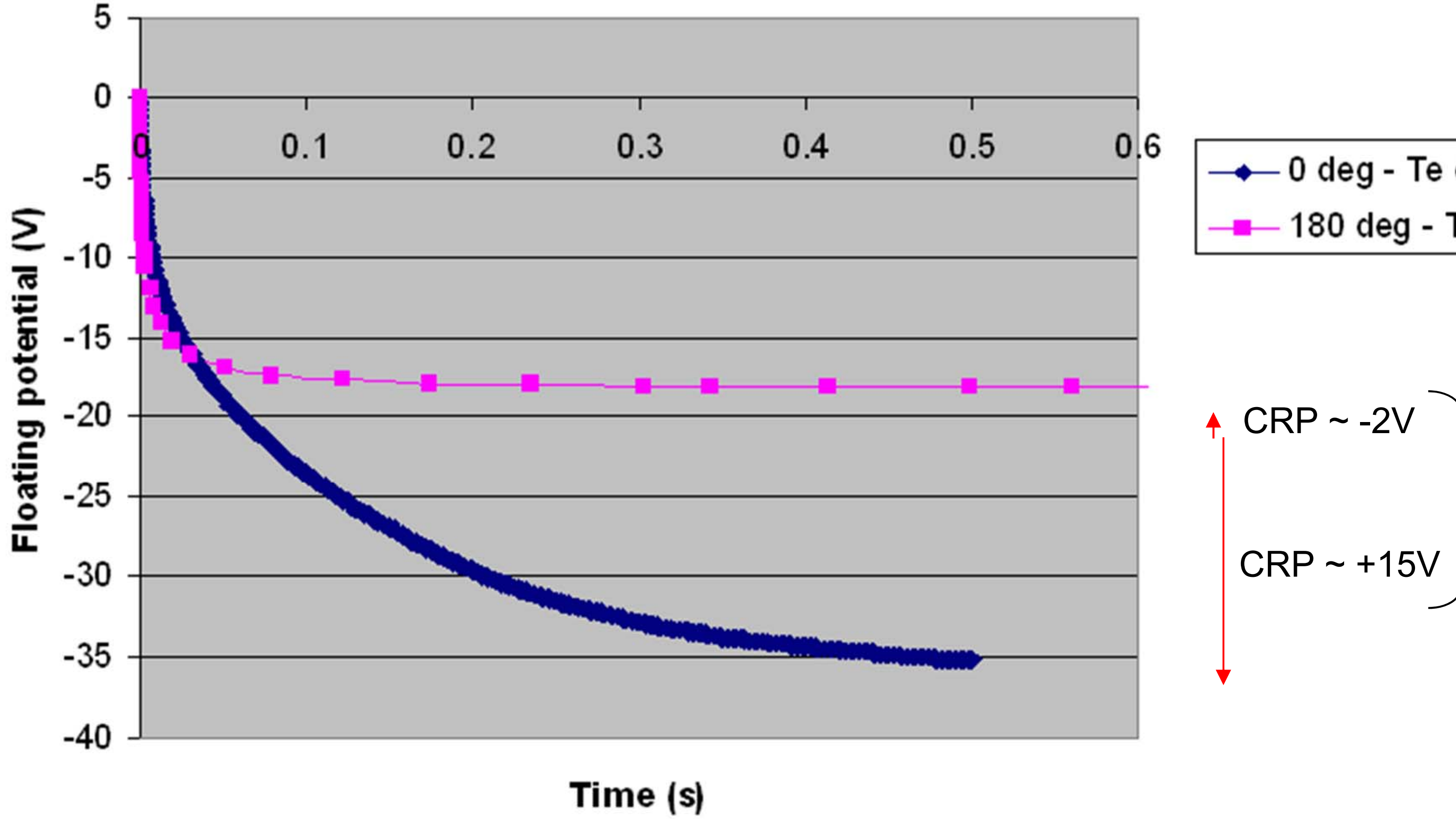




Variable $T_e$



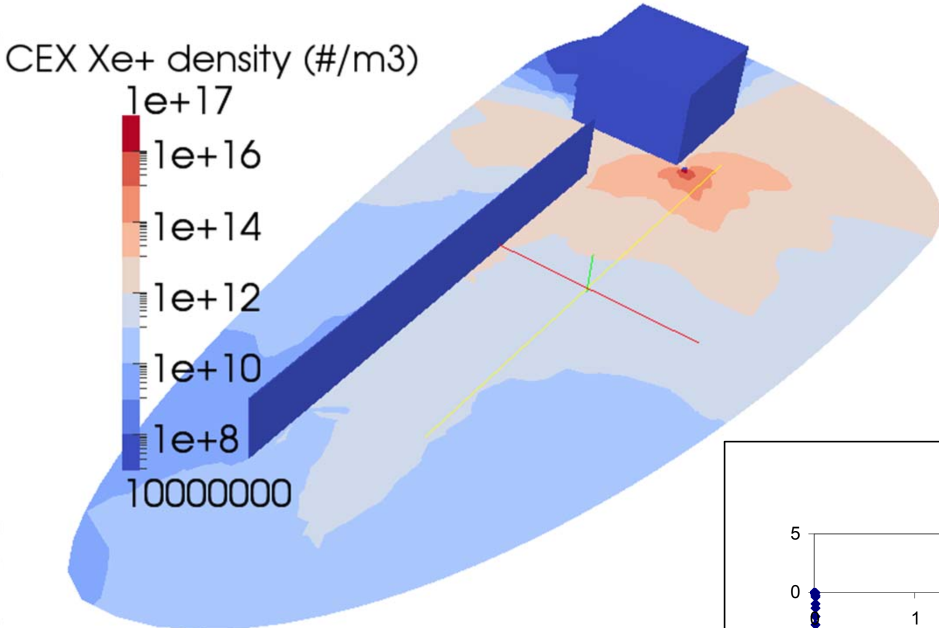
## SPIS simulations of Smart1 - Evolution of spacecraft ground potential

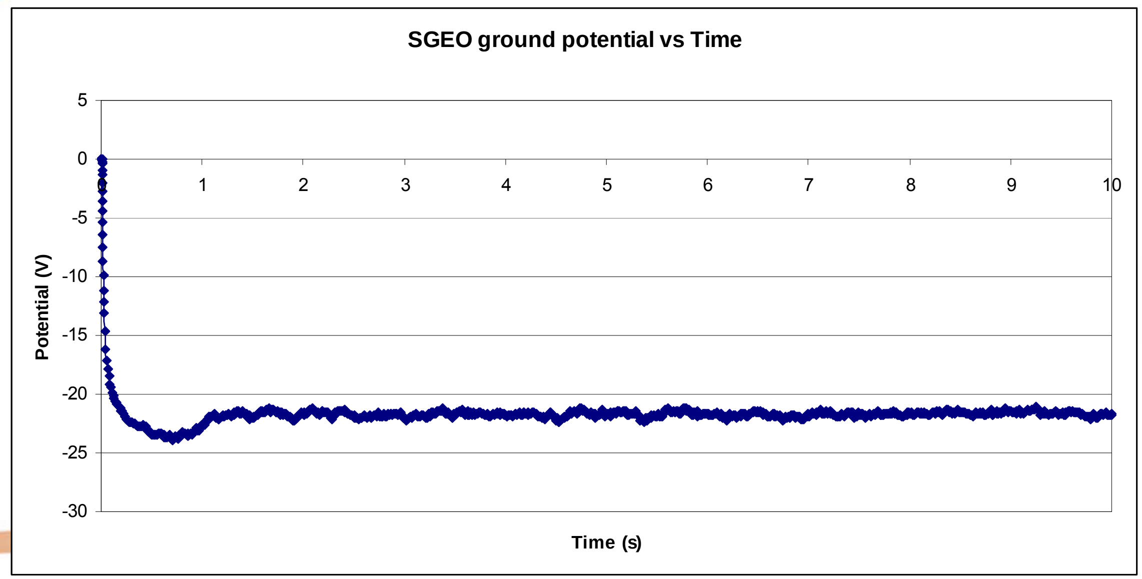



In-flight -2 to 13V but peak around 130°

# SmallGEO simulation



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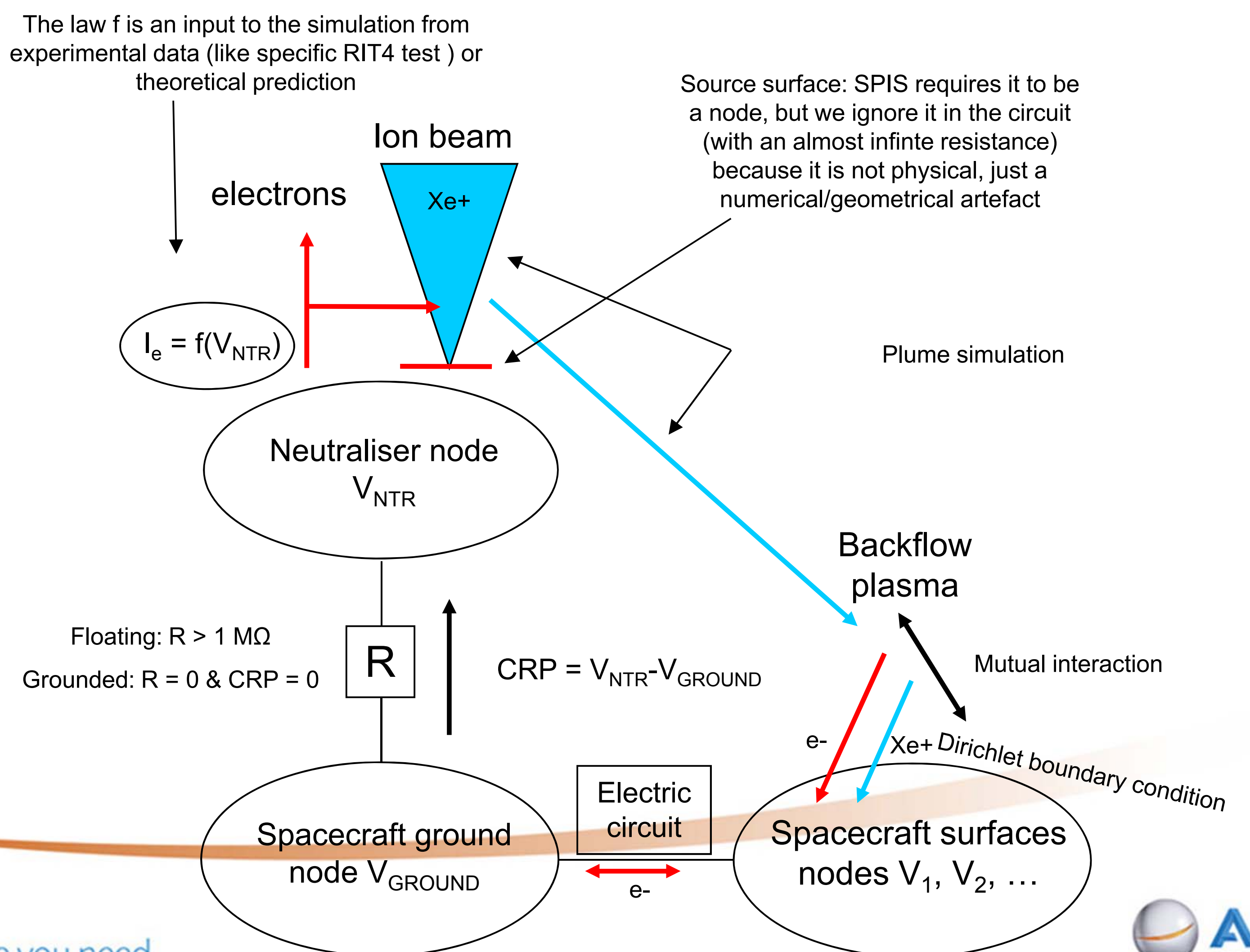
# Approach to predict the CRP taking into account the neutraliser grounding conf.



# Conclusion and ways forward

- Plume models for many EP thrusters have been implemented in SPIS and validated
  - Plume axis: very good fit of experimental data
  - High angles: same order of magnitude as on-ground data but slight underestimation (ratio ~1 to 4)

- The floating potentials calculated for Smart1 with « rough » modelling are in line with in-flight measurements

# Next months activities

- ONERA: provide Spis-Science developments for more realistic and easy modelling of $e^-$ current collected by IC + probe modelling (RPA…)
- Astrium/ONERA: make Poisson solver compatible with variable electron temperature
- Astrium/ONERA: merge AISEPS developments into current branch of SpisNum (including Spis-Science and Spis-GEO)
- Astrium: update Smart1 simulations using these developments