# Focus on physical modelling and usability improvements of SPIS in the frame of SPIS-ASPOC and SPIS-LISA projects

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# Introduction and context

- SPIS-ASPOC:
  - ESA ITT AO/1-8620/16/NL/LF “Modelling of Electrostatic Environment of Ion Emitting Spacecraft”
  - New models to improve the physical modelling of the electrostatic cleanliness of an ion emitting spacecraft
  - Improvement of the performance and usability
  - Validation wrt Cluster spacecraft inflight data

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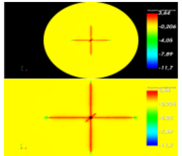
- Management
- Software requirements
- Physical model developments
- Numerical core improvements & development
- ☑ Sofware verification

LPP

- User requirements
- ☑ Validation with cluster data



ARTENUM, PARIS
Science & Groupware

- Software requirements
- User interface improvements
- Packaging

- SPIS-LISA:
  - ESA ITT AO/1-9266/18/NL/IB/gg “Development and Validation of a Contamination package in SPIS for liquid based electrical propulsion subsystems for LISA : SPIS-Microthruster project”
  - Improve or develop models of erosion and contamination, liquid ion source models and droplet behavior
  - Validation wrt experimental data / application to LISA mission

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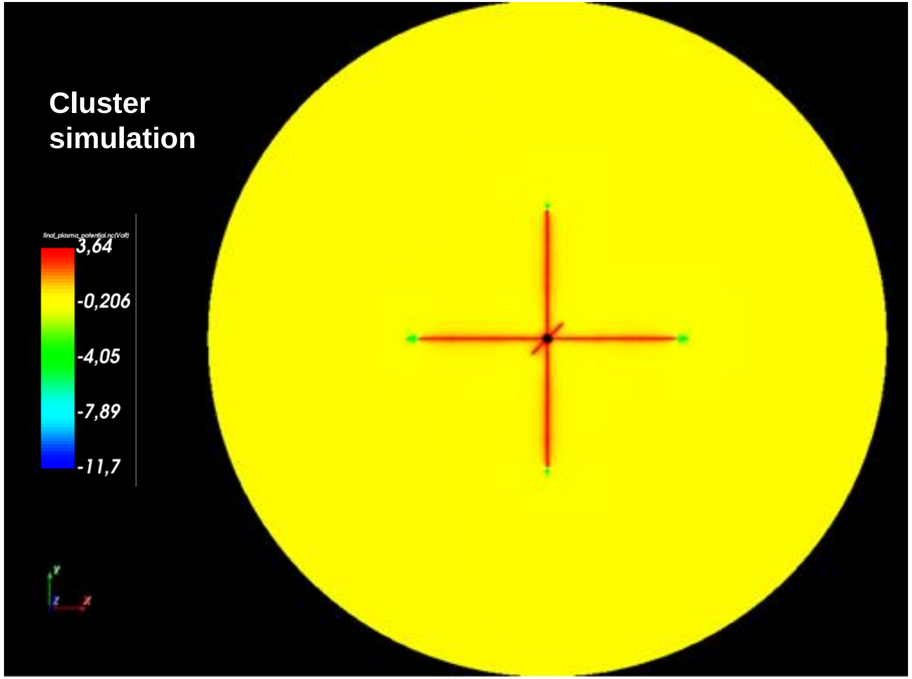
AIRBUS
DEFENCE & SPACE

- User requirements
- ☑ Validation

ThalesAlenia
a Thales / Leonardo company
Space

- User requirements
- ☑ Validation

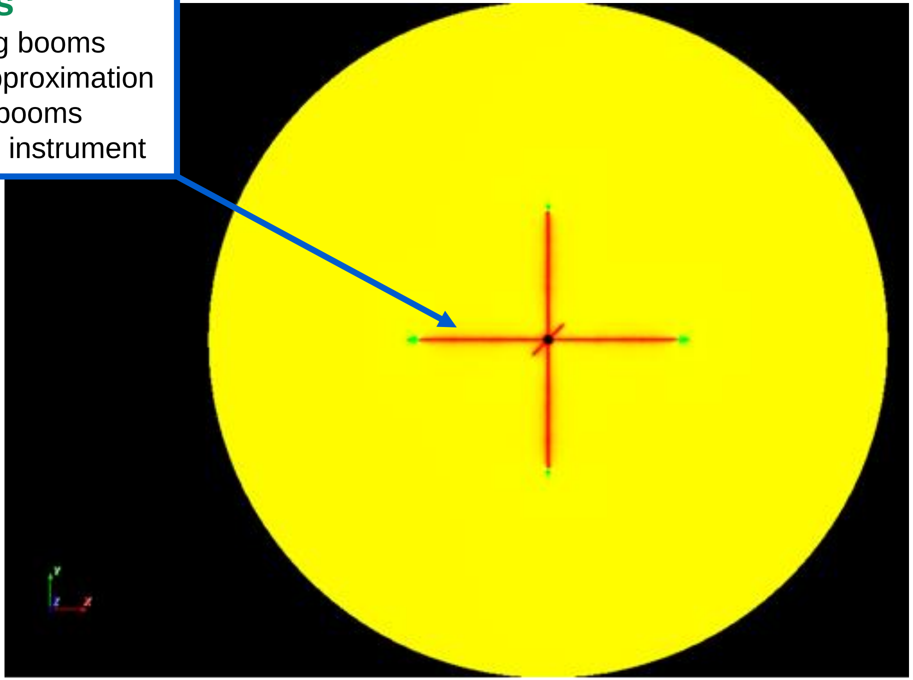
# SPIS-EP Limitations (version 6.0)



# SPIS-EP Limitations (version 6.0)

**Thin wires**

- Bending booms
- Wire approximation
- End of booms
- Wire as instrument



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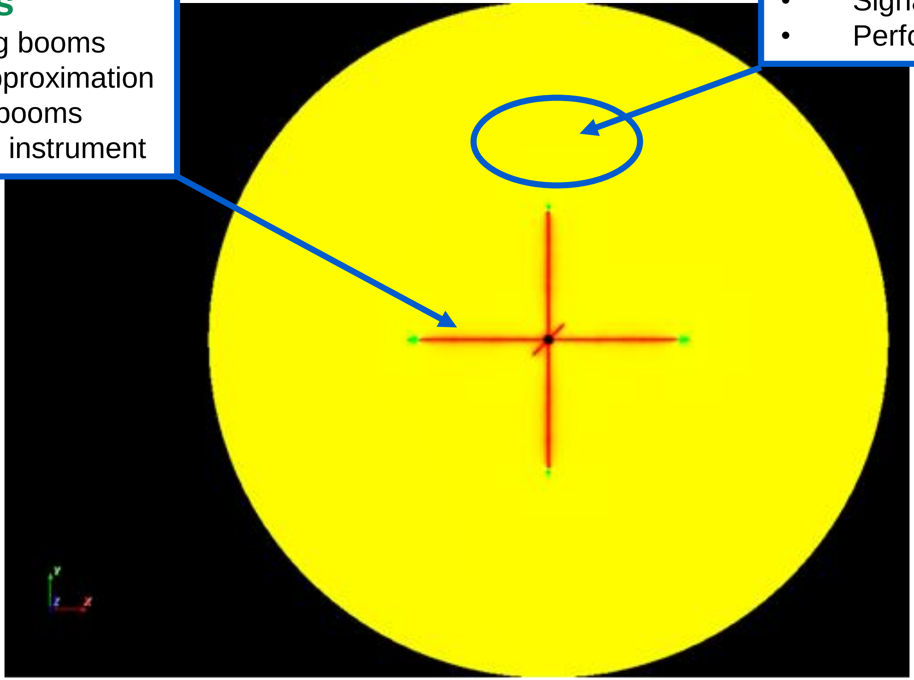

**Low noise distributions**
- PIC perturbative for environment
- Signal/noise improvement
- Performance

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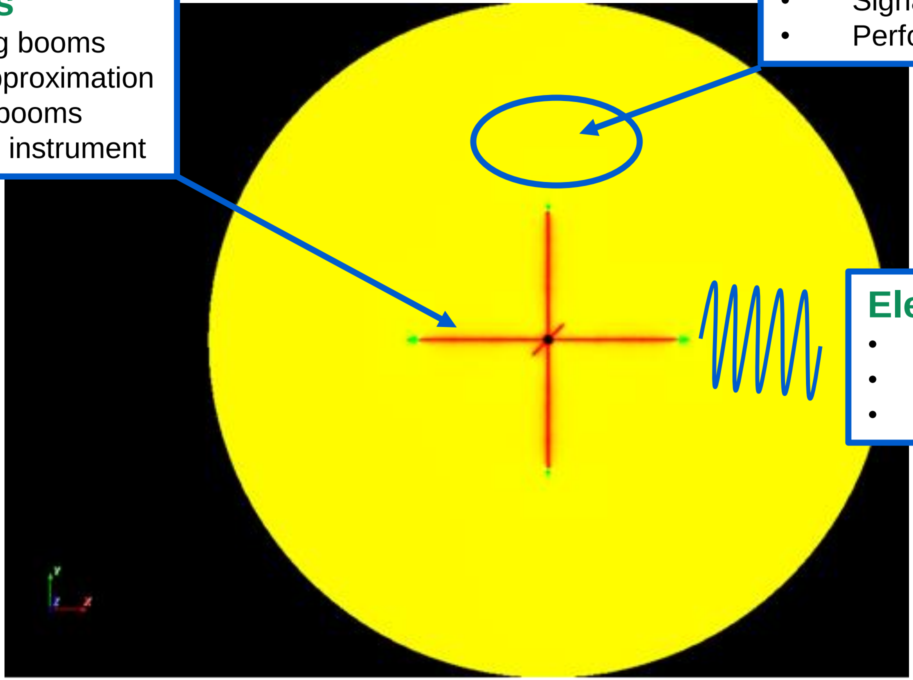


**Electro magnetic fields/waves**
- Transport EM waves
- Variable B and E
- Effect of B and E

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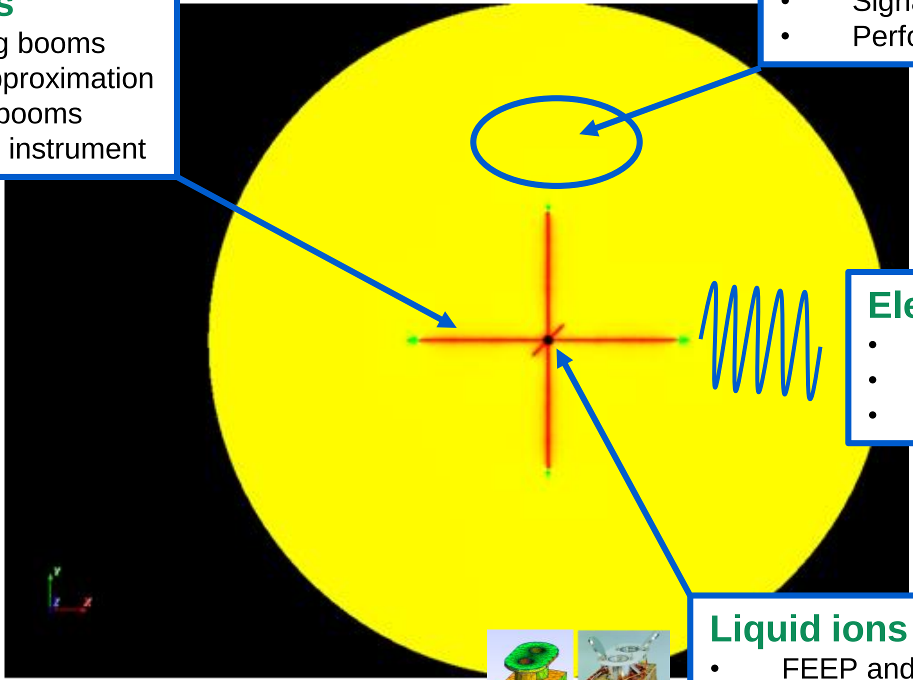

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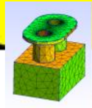

**Liquid ions sources**
- FEEP and colloids
- ASPOC
- Contamination and effects

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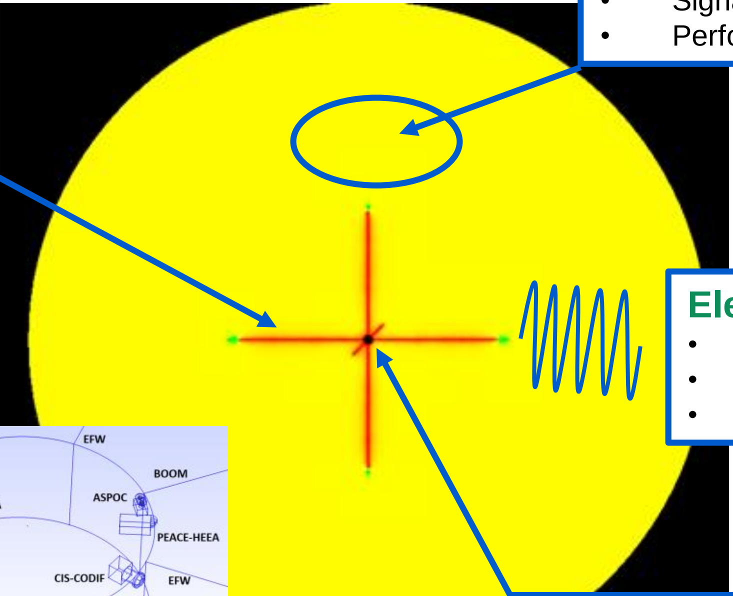

### Thin wires
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### Electro magnetic fields/waves
- Transport EM waves
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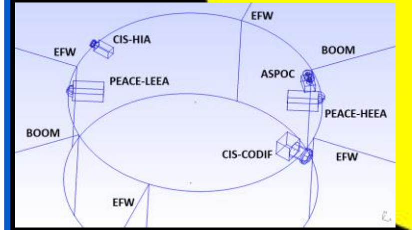
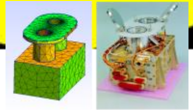
### Scientific instruments
- Impedance probe
- Langmuir probe
- Elec. Antenna
- Search Coils
- Particle detector
- Potential/current probes



### Liquid ions sources
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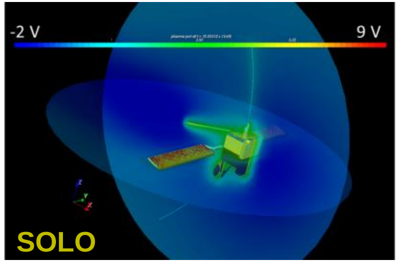
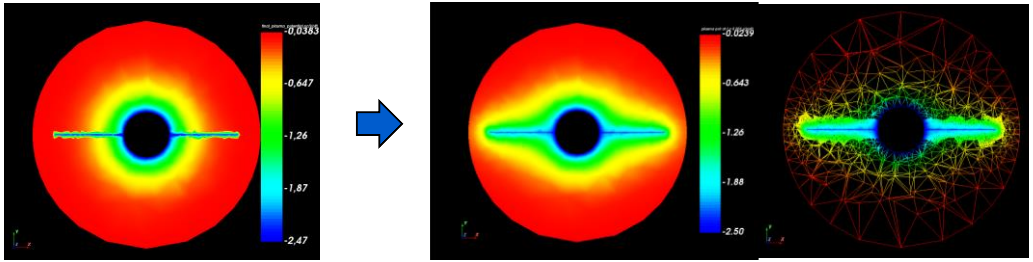
# Thin wires

- No changes for the definition in UI
- Thin wire approximation has been rewritten and improved to allow:

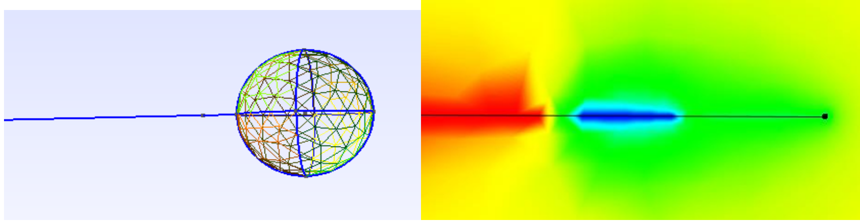
**1) Bending booms**



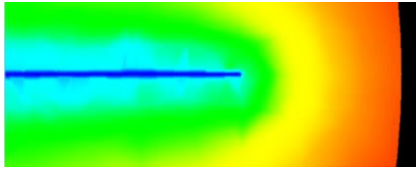

**2) Wire approximation + mesh refinement**




**3) Connection between wires and surfaces**

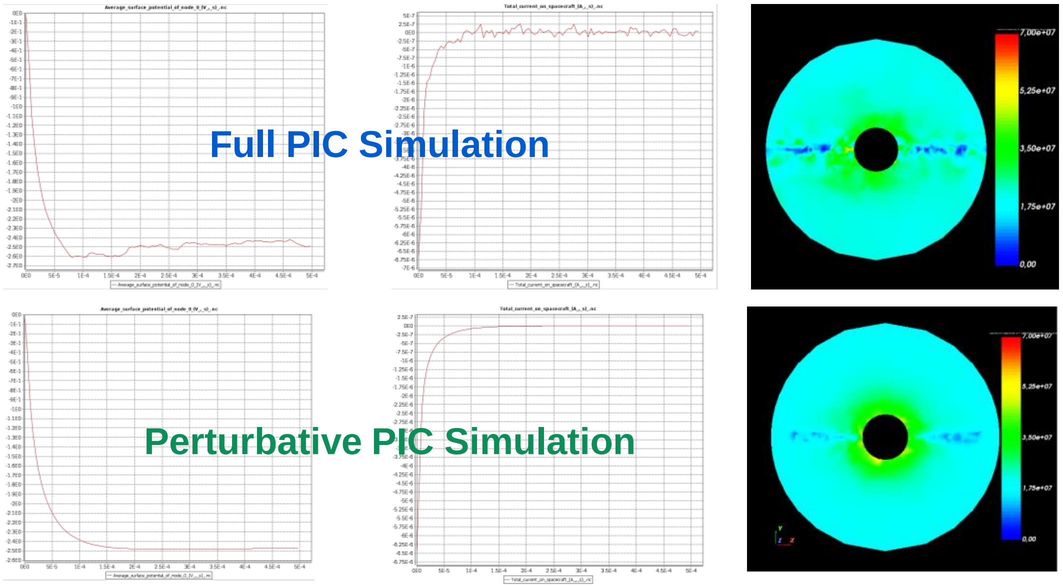


**4) End of boom and radius change improvements**



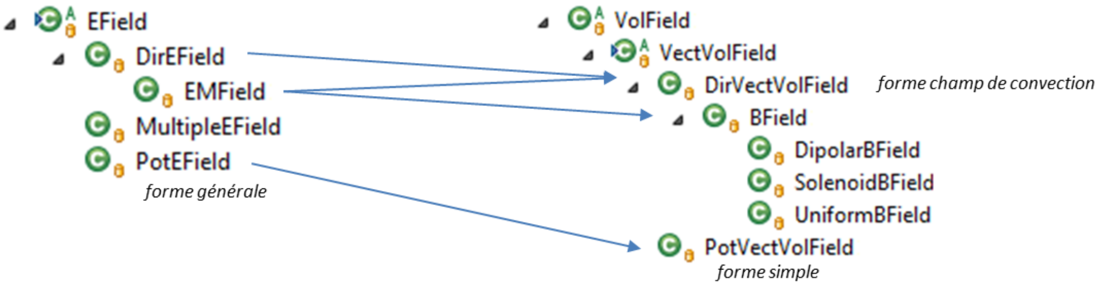
# Low noise distributions based on PIC perturbative method

- *PICPerturbationToAnalyticalVolDistrib*: uses perturbative PIC model to correct analytical distributions.
- Analytical distributions for ions or electrons (from environment only / not for sources):
  - KineticMaxwellBoltzmannVolDistrib: Maxwell Boltzman approximation but with a better modelling of the density and temperature variations as a function of the potential (temperature computed to conserve total energy in an attractive potential: kT=kT0-qV)
  - DriftingMBVolDistrib: an extension of the above for drifting plasma. The geometrical effects due to the drift (e.g. wakes) computed using test particles
- Developped by Oriol Jorba Ferro (thesis 2018) to model Electric field probes for the TARANIS mission
- Now integrated in SPIS and tested with:
  - Wire approximation
  - Magnetic fields
- Useful to simulate cold and dense plasmas usually modelled with PIC method:
  - Solar wind, LEO plasmas, …
  - Decrease the noise / increase the performance
- Not an implicit method → Debye length and plasma frequency have to be solved
- Cannot be used for a source at the surface



# Electromagnetic sources and solver

- *API modified so that distribution accept the most generic Efield class as input*
- *New capabilities for generalized EM fields:*
  - Electric fields resulting from Poisson equation (Electrostatic)
  - Imposed static or variable electric field at the boundary limits or in volume (resulting from the plasma environment)
  - Static or variable magnetic fields imposed in volume (uniform, dipolar, solenoid)
  - EM waves imposed in volumes
  - EM waves resulting from MHD approximation

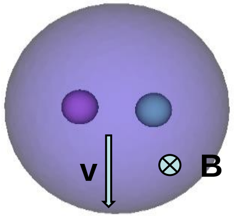


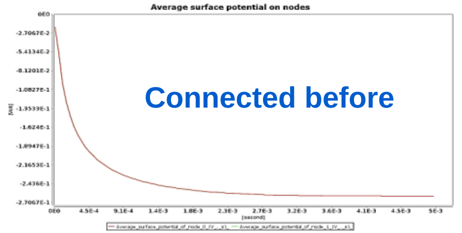

- Solver with generalized Ohm's law details
  - Maxwell equation with implicit electron current
  - Assuming inertialess electrons
  - Non-collisionnal plasma
  - Can be used to create or transport EM waves in plasma at ions and/or plasma acoustic frequency
  - Cannot be used to model electron instabilities or waves transport at the electron frequency

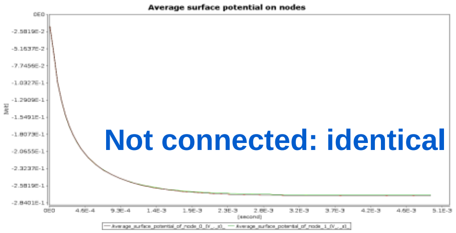
$$\begin{cases} \left(1+\frac{v_A^2}{c^2}+\frac{v_A^2\lambda_i^2}{c^2\delta x^2\left(1-exp^{(-\delta x/\lambda_e)}\right)^2}\right)E_V = \frac{(\nabla\wedge B_S)\wedge B_V}{\mu_0 e n_e}.\left(1-exp^{(-\delta x/\lambda_e)}\right) - \frac{J_{i;V}\wedge B_V}{e n_e}\{+E_{s;V}\} \\ \nabla.\mathrm{E}_{s;V} = \frac{\rho_N}{\varepsilon_0} \\ \frac{\partial B_V}{\partial t} = \nabla\wedge E_S.\left(1-exp^{(-\delta x/\lambda_e)}\right).\left(1-exp^{(-\Omega_{ce}\delta t)}\right) \end{cases}$$

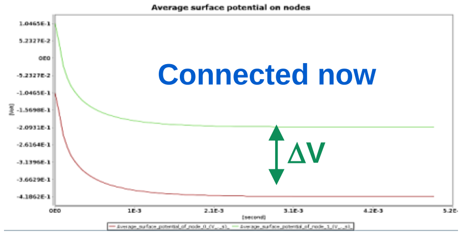
# Magnetic coupling

- Improvements for convection field on surfaces
- Test with two metallic spheres:
  - connected or not by a resistor.
  - Could not be treated before.

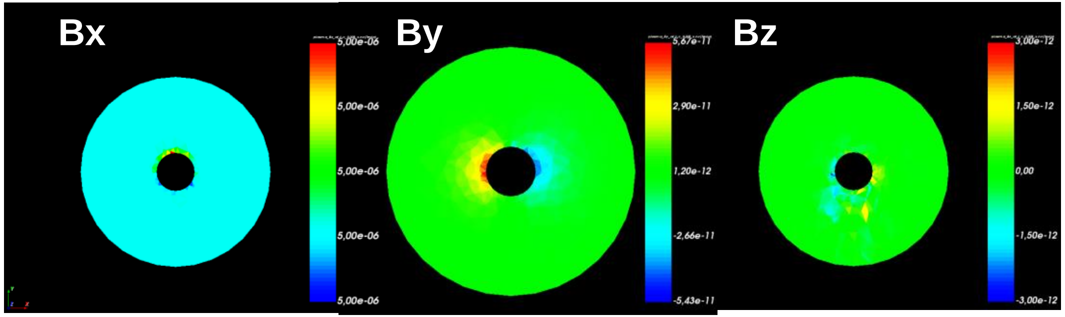


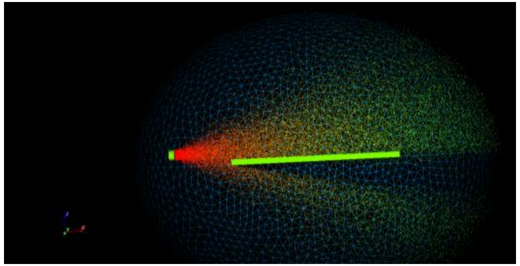

- EM solver test case:
  - Bx=5µT
  - Vsc=7500 m/s (y)
- The perturbation of the magnetic field is consistent with a drapping around the sphere.



# Liquid Ion Sources

- FEEP and Colloid Thrusters / also for ASPOC
  - Fitting model based on experimental parameters
  - Equivalent model for electrospray thruster
- User can also directly define the mass flow, current and/or voltage

- Thruster: In-LMIS-2
  - onsetVoltage = 1000.0 [V]
  - cathodeEmittedCurrent = 0.0 [A]
  - Cathode = FieldEmissionCathode
  - criticalTemperature = 600.0 [K]
  - criticalCurrent = 6.0E-6 [A]
  - cathodeVoltage = 770.0 [V]
  - cathodeBeta = 115.0
  - impedance = 2500000.0 [ohm]
  - acceleration_voltage = 5000.0 [V]
  - interactorType = FEEP
  - e-Temperature = 5.0 [eV]
  - voltage = 5000.0 [V]
  - e-Model = PICVolDistrib
  - emitterNumber = 1.0
  - temperature = 300.0 [K]
  - efficiencyExponent = 0.93
  - cathodeWorkFunction = 5.1 [eV]
  - cathodeEmitterArea = 2.0E-15 [m2]
  - interactorFlag = 1.0
  - cathodeEmitterGapDistance = 1.0E-5 [m]
- In+-2
- droplet-2



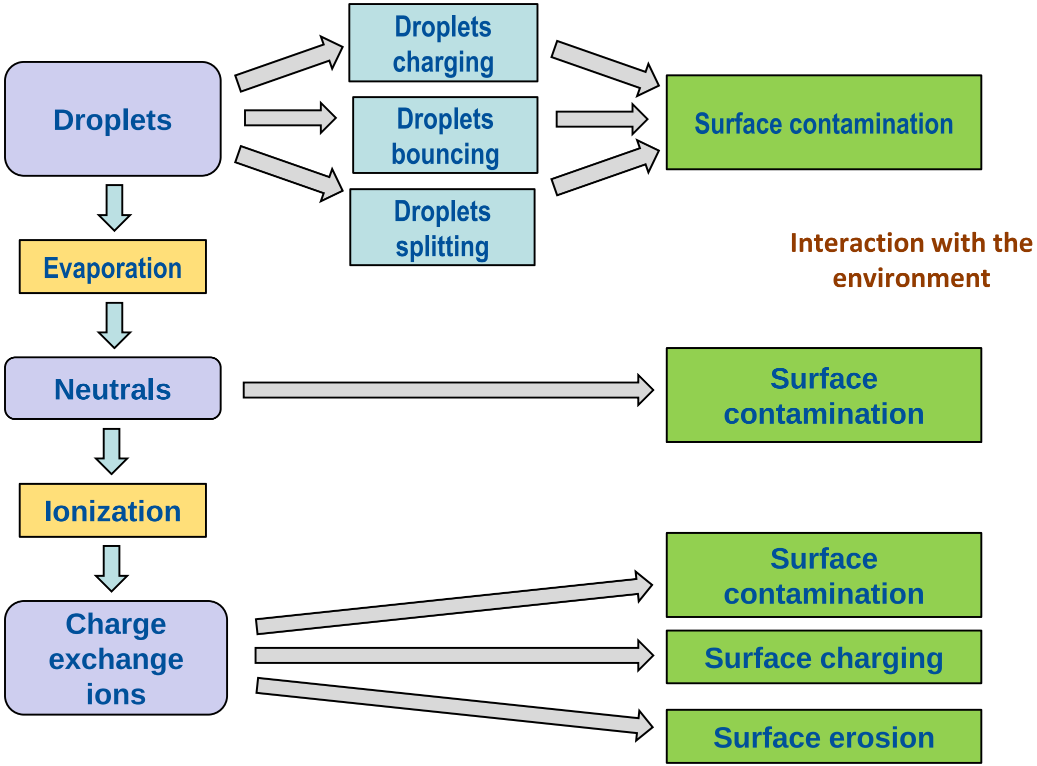
FEEP model:

$$\begin{cases} \text{Particles (ions and droplet) emission velocity}: \; v = \sqrt{\dfrac{q\Phi_a}{m}} \\ \text{Total emitted current}: \; I = \dfrac{\left(\dfrac{\phi_e}{\phi_{on}} - 1\right)^{-\beta}}{Z} \\ \text{Masse fraction of droplet}: \; \eta = \left(\dfrac{I}{I_c}\right)^{\alpha} \dfrac{f(T)}{\phi_e} \\ f(T) = \dfrac{1.04}{2} - \dfrac{1.04\,\mathrm{atan}(T - 562K)}{\pi} \\ \alpha = 1 - 2\beta \end{cases}$$

For LMIS thruster:

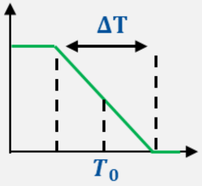
- $\beta = 115$
- $I_c = 6.0\ \mu A$
- $Z = 2.5\ M\Omega$
- $\phi_a = 5000\ V$
- $\phi_{on} = 1000\ \mathrm{V}$
- $\phi_e = 5000\ V$

# Contamination modelling



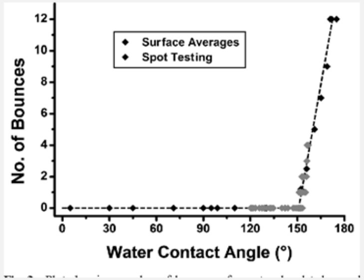

## Molecular contamination

$$S = \begin{cases} 1 & T < T_0 - 0.5\Delta T \\ 0.5 - (T - T_0) * \Delta T^{-1} & \\ 0 & T > T_0 + 0.5/\Delta T \end{cases}$$



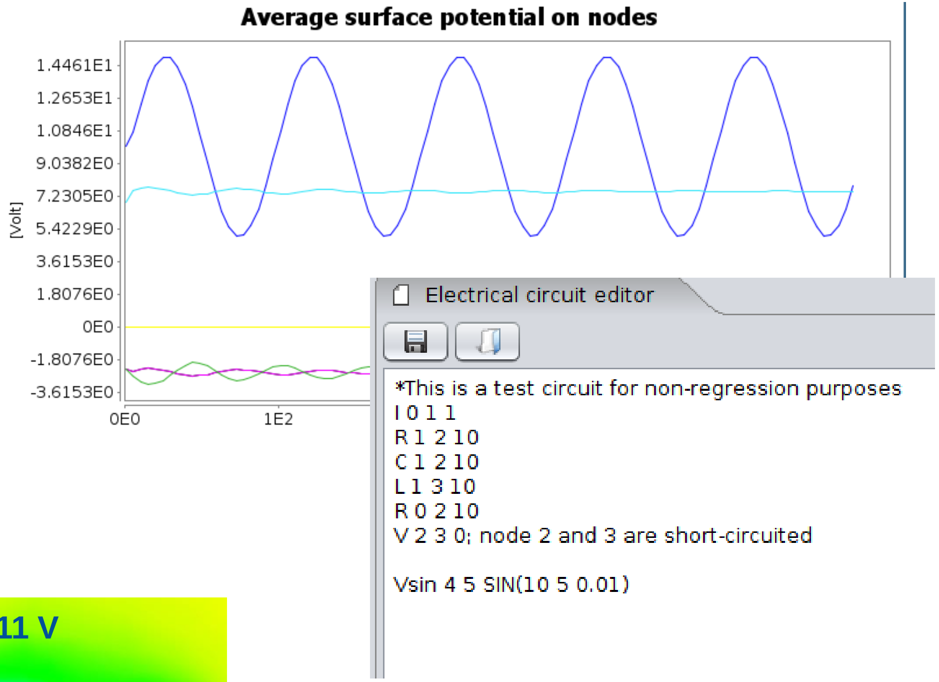

## Droplet bouncing on surface

$$S = 1 - \exp\left(-\frac{STK}{\gamma.(1\text{Å})^2}\right)$$



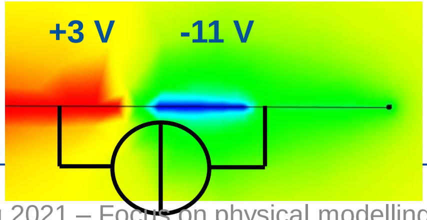
# Improvement of electric circuit solver

- Improvement of the circuit solver performance and stability
  - Faster computation in most of the cases
  - Much more stable for all the applications
  - BUT: some cases are longer to run (previously at the limit of the stability)
- Accept SPICE netlist:
  - can define models for component, names and put comments
  - accept time varying I and V generators
  - includes SPICE's SIN, PULSE, EXP and PWL (piece wise linear)
  - allow comments
  - allow for the definition of models
  - easy to extend (simple API, based on the plugin philosophy)



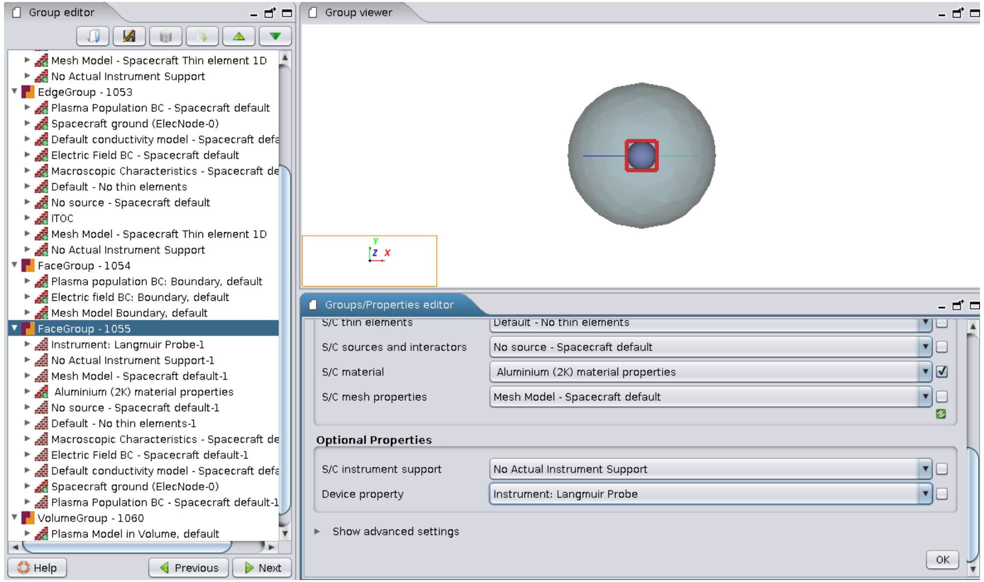

- Included in the NRC test case, run in 4sec., included as a functional test (test at compilation)
- Possible to model current generator

→ useful for potential probes



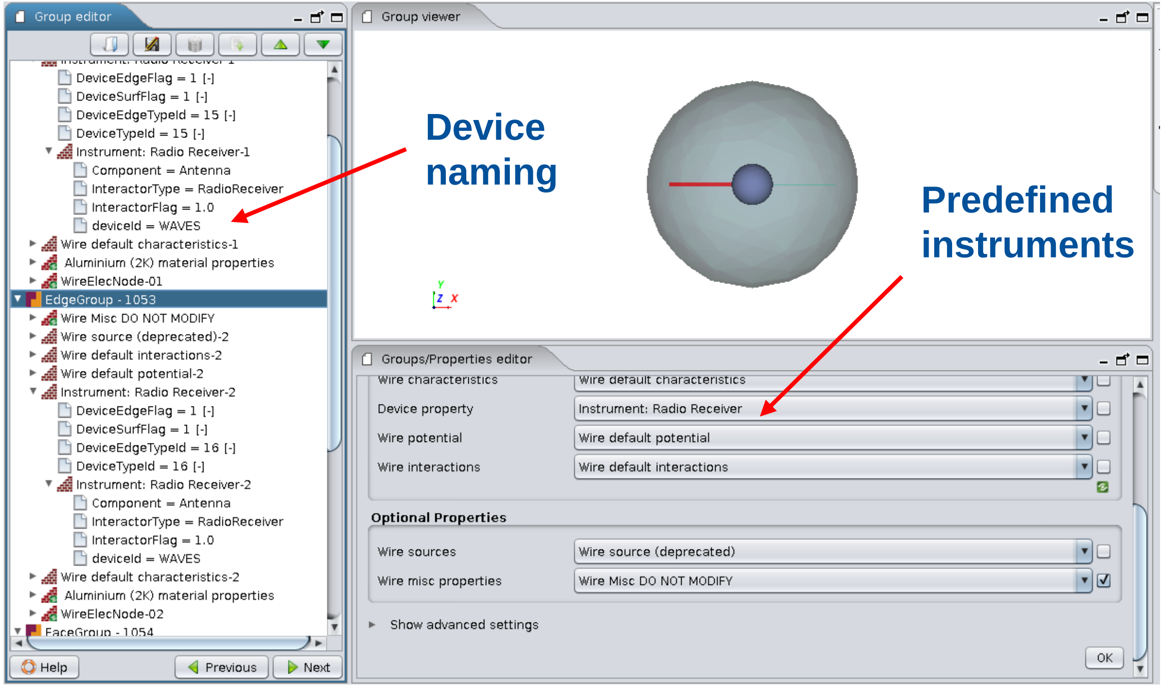
# Instruments as devices at the Group Editor stage

- Possibility to associate an instrument to a spacecraft element directly in the group editor
  - To avoid the two stage definition of instrument support zone + instrument
  - To have pre-defined instrument settings for advanced users
- To associate several surfaces to the same instrument with the « deviceId » property. Usefull for multi sensor instruments.
- To combine instruments
- To associate “certain” instruments to wire elements
- Predefined instruments:
  - Impedance probe
  - Langmuir probe
  - Elec. Antenna
  - Search Coils
  - Particle detector
  - Potential/current probes



# Antenna – Radio Receiver

- Electric field sensors defined by setting the “InteractorType” to “WaveSensor”
  - Define Min and Max frequencies
  - Wire instruments
  - Electric field vs time



# Antenna – Radio Receiver

- Electric field sensors defined by setting the “InteractorType” to “WaveSensor”
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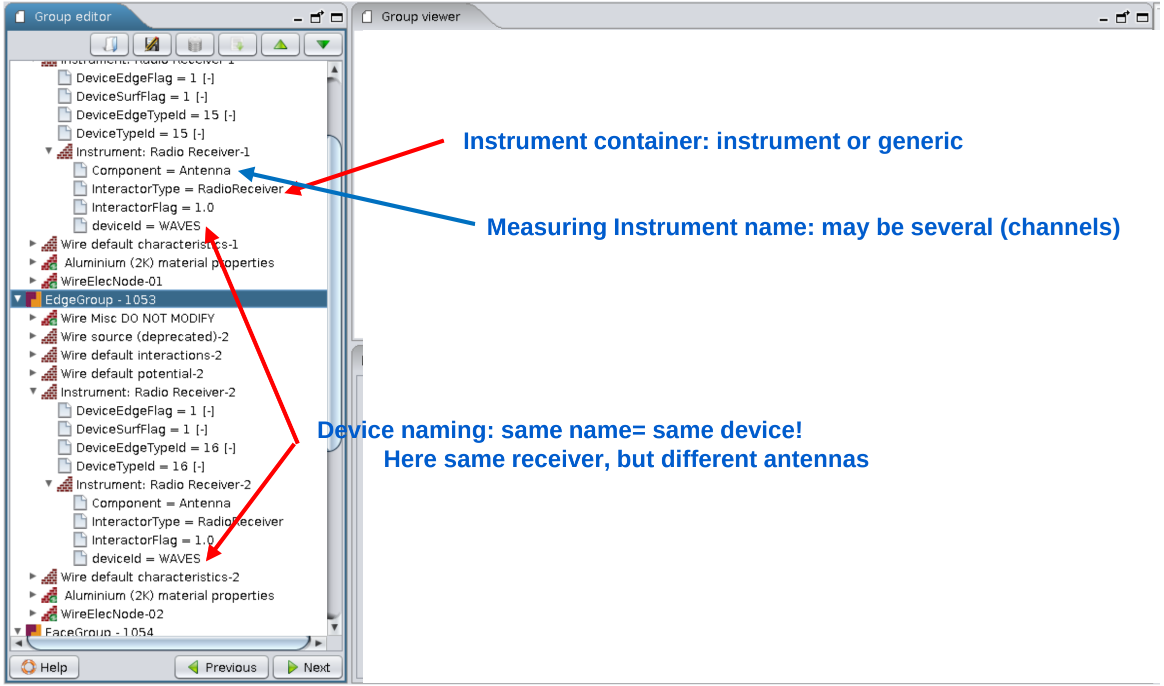
- Synthetic antennas created by combination of antenna



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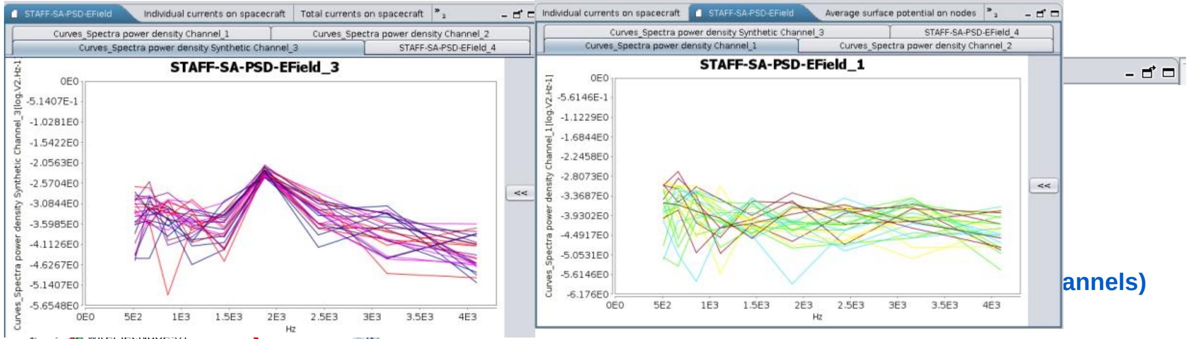
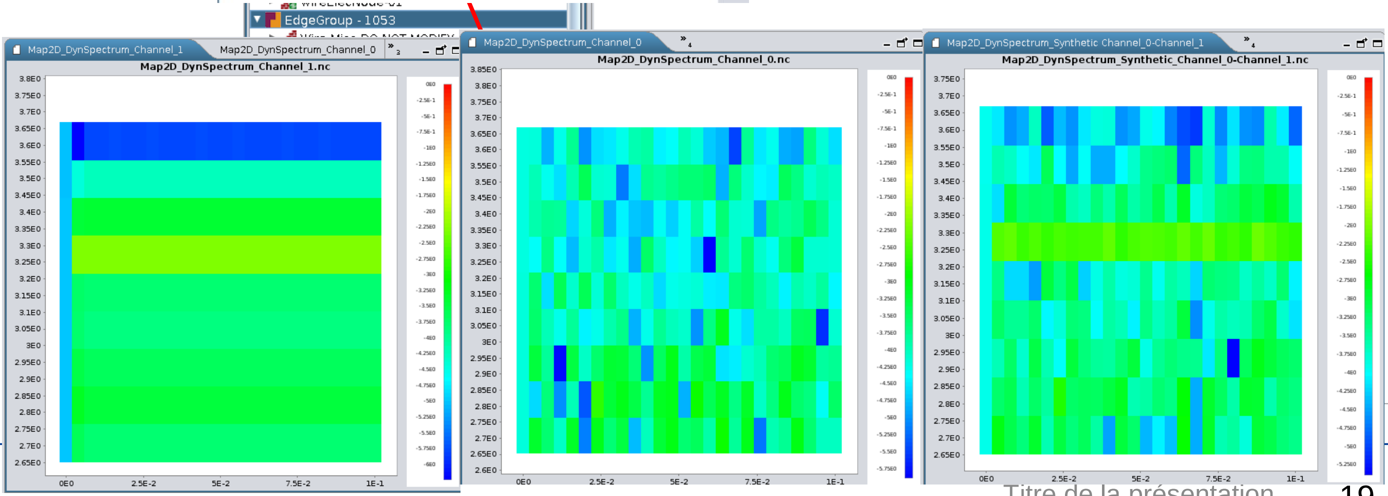
- Synthetic antennas created by combination of antenna

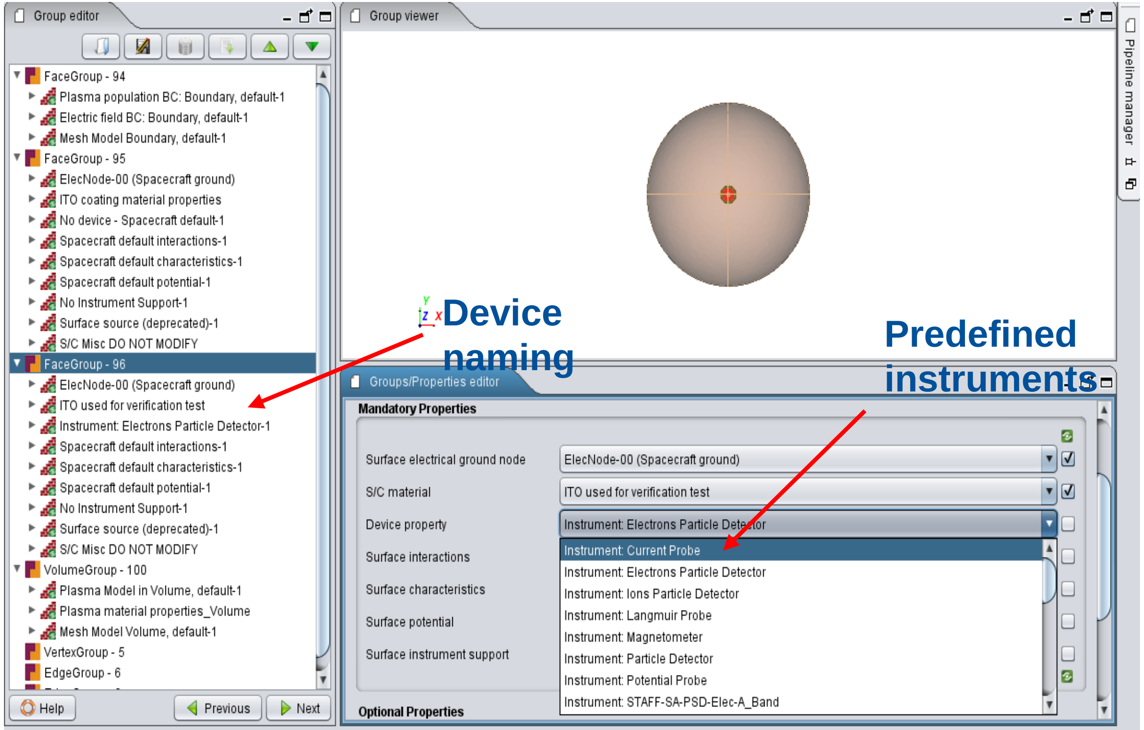
- Outputs:
  - Frequency Spectra
  - Dynamic spectra



# Particle detector

- Single and multi-channel particle detector as a device
  - Ion Particle Detector: that’s detect the ions1 and ions2 popullations
  - Electron Particle Detector: that’s detect elec1, elect2, photoElec and secondaryElec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# Particle detector

- Electric field sensors defined by setting the “InteractorType” to “WaveSensor”
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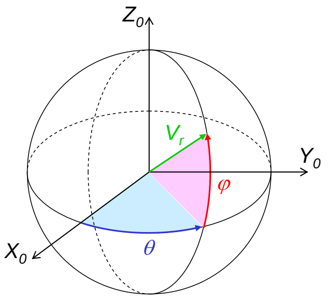
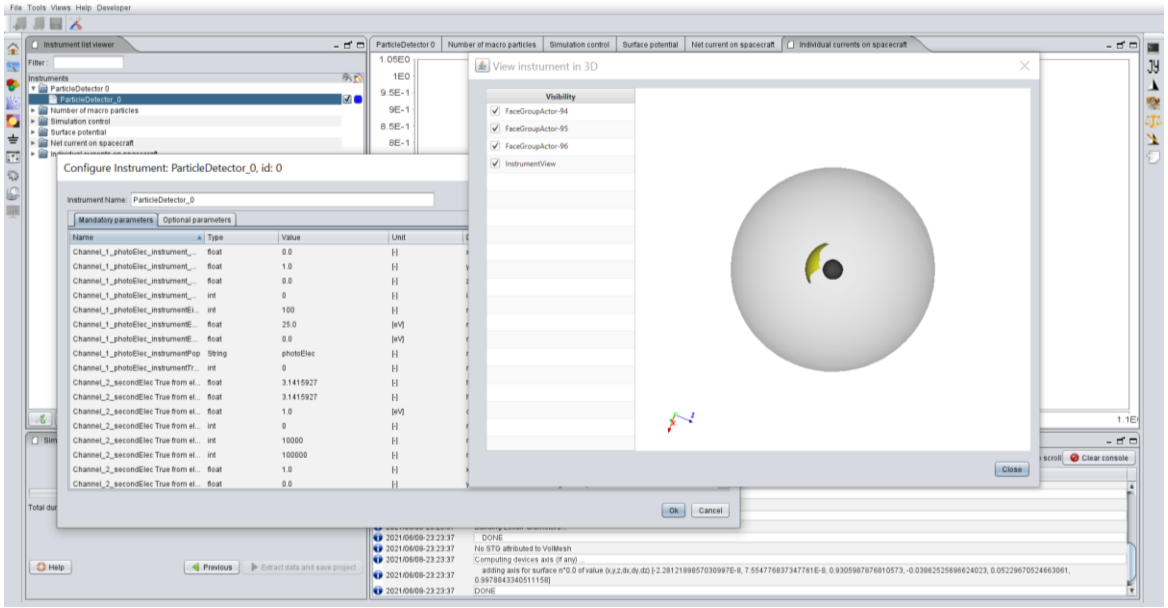
  - Electric field vs time

- Create a multichannel PD in the live monitoring

- Possibility to visualize the fields of view



# Particle detector

- Electric field sensors defined by setting the “InteractorType” to “WaveSensor”
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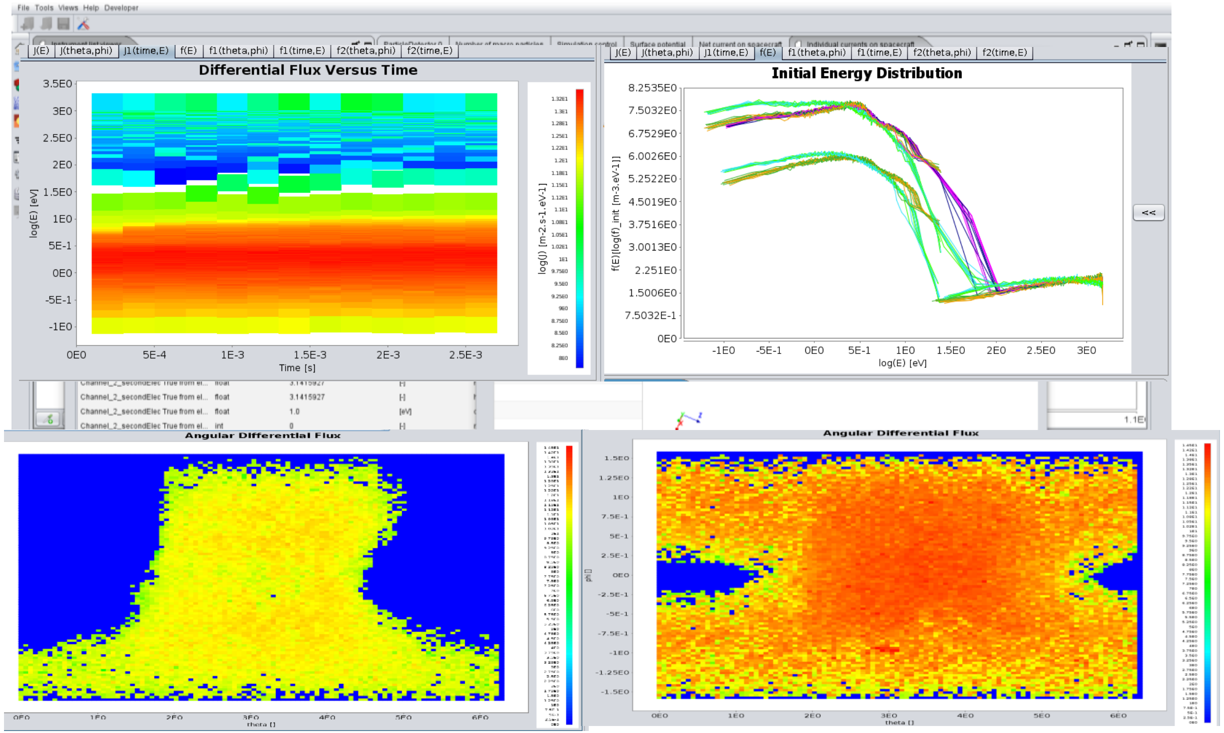
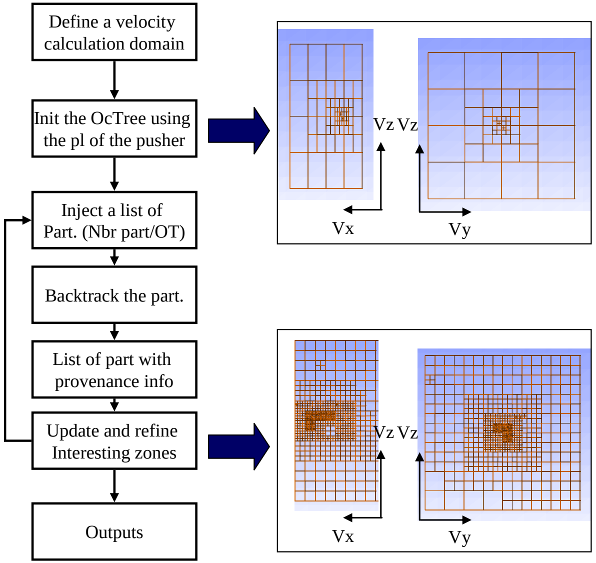
  - Electric field vs time
- Create a multichannel PD in the live monitoring
- Possibility to visualize the fields of view
- All the results for all individual channel + concatenated results for all the channels



# Particle detector

- Electric field sensors defined by setting the "InteractorType" to "WaveSensor"
  - Define Min and Max frequencies
  - Wire instruments
  - Electric field vs time
- Create a multichannel PD in the live monitoring
- Possibility to visualize the fields of view
- All the results for all individual channel + concatenated results for all the channels
- Update of the OcTree algorithm and the OcTree splitting heuristic
- Possibility for advance user to add by default multichannel instrument in the SPIS catalog




Cost function written as:

$COST \sim f^{a1} \text{ x } (v.n)^{a2} \text{ x } \langle f\rangle^{a3}\, dv_x\, dv_y\, dv_z$

Or : $COST \sim f^{a1} \text{ x } v^{a2} \text{ x } \langle f\rangle^{a3}\, dv_x\, dv_y\, dv_z$

With:

- distribution value $f(v_x,v_y,v_z)$
- moment value v.$n$ or v
- dispersion value $\langle f(v_x,v_y,v_z)\rangle$

And power factor:

- distribution value power factor a1
- moment value power factor a2
- dispersion value power factor a3

Configure Instrument: ParticleDetector_0, id: 0

Instrument Name: ParticleDetector_0 View in 3D

Mandatory parameters | Optional parameters

| Name | Type | Value | Unit | Description |
|---|---|---|---|---|
| instrument_OcTreeHeuristic_normal_X | float | 1.0 | [-] | User define surface normal for the OcTree heuristic (default: 1.0 |
| instrument_OcTreeHeuristic_normal_Y | float | 0.0 | [-] | User define surface normal for the OcTree heuristic (default: 0.0 |
| instrument_OcTreeHeuristic_normal_Z | float | 0.0 | [-] | User define surface normal for the OcTree heuristic (default: 0.0 |
| instrument_OcTreeHeuristic_powerFactorDispersion | int | 1 | [-] | Power law on the dispersion value for the OcTree heuristic (default: 1.0 |
| instrument_OcTreeHeuristic_powerFactorValue | int | 1 | [-] | Power law dependance of the Octree value (default: 1.0 |
| instrument_OcTreeHeuristic_powerMomentValue | int | 1 | [-] | Power law dependance of the Octree moment value - 1 equal the simple integral (def... |
| instrument_OcTreeHeuristic_useNormal | int | 0 | [-] | Use surface normal for the OcTree heuristic (default: 0 = No, 1 = Detector basis, 2 = ... |
| instrument_UseLogScale_Energy | int | 1 | [-] | Use log scale for energy scales in outputs (default: 0 = Linear, 1 = Log |
| instrument_UseLogScale_Value | int | 1 | [-] | Use log scale for value scales (f and J) in outputs (default: 0 = Linear, 1 = Log |
| instrumentSupportId | int | -1 | [-] | support index of a particle detector on the spacecraft |

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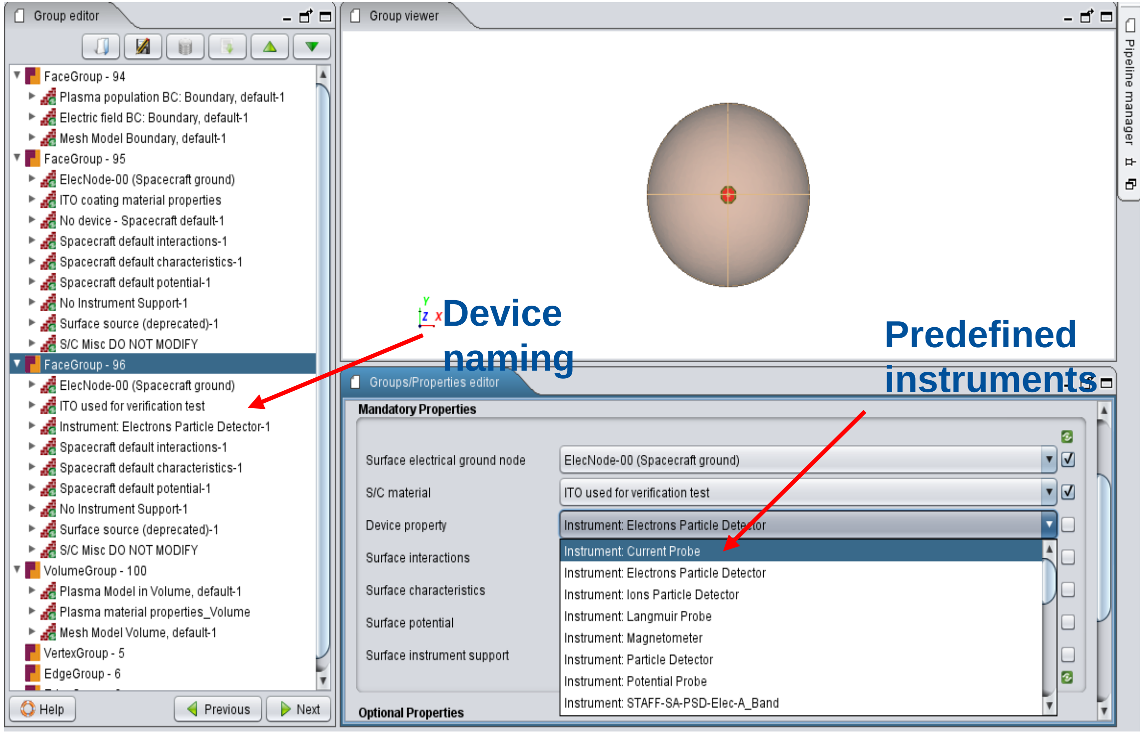
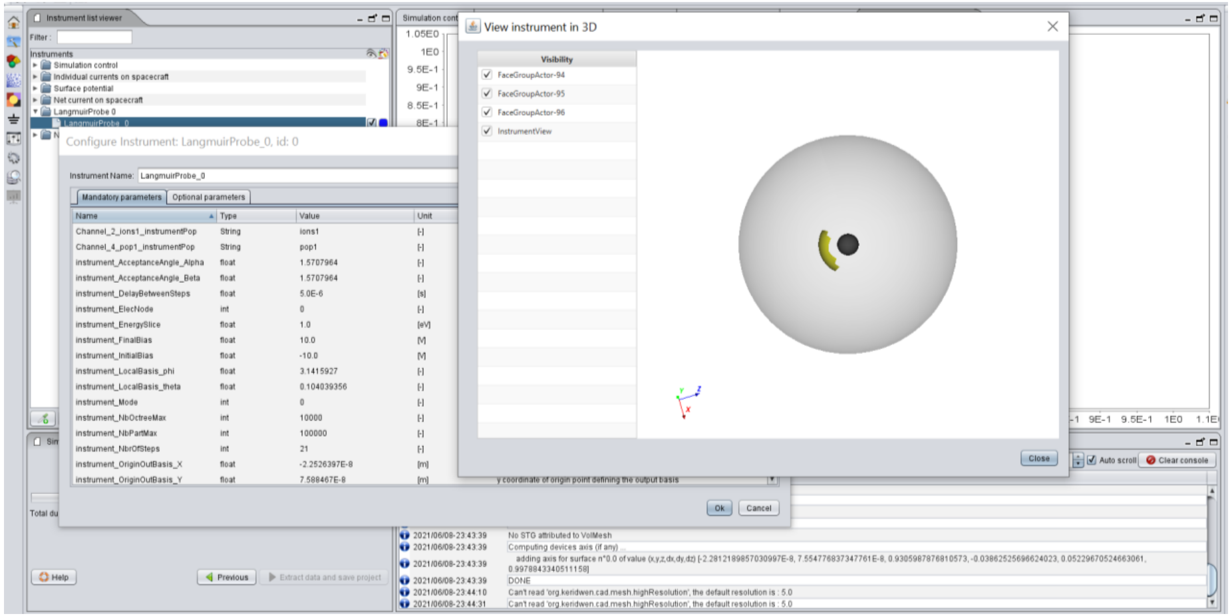
# Langmuir probe

- Single and multi-channel particle detector as a device
  - Single channel Langmuir probe by defaults
  - Easy to add channel
  - Improvement of IV Sweep



# Langmuir probe

- Single and multi-channel particle detector as a device
  - Single channel Langmuir probe by defaults
  - Easy to add channel
  - Improvement of IV Sweep
- Create a multichannel PD in the live monitoring
- Possibility to visualize the fields of view



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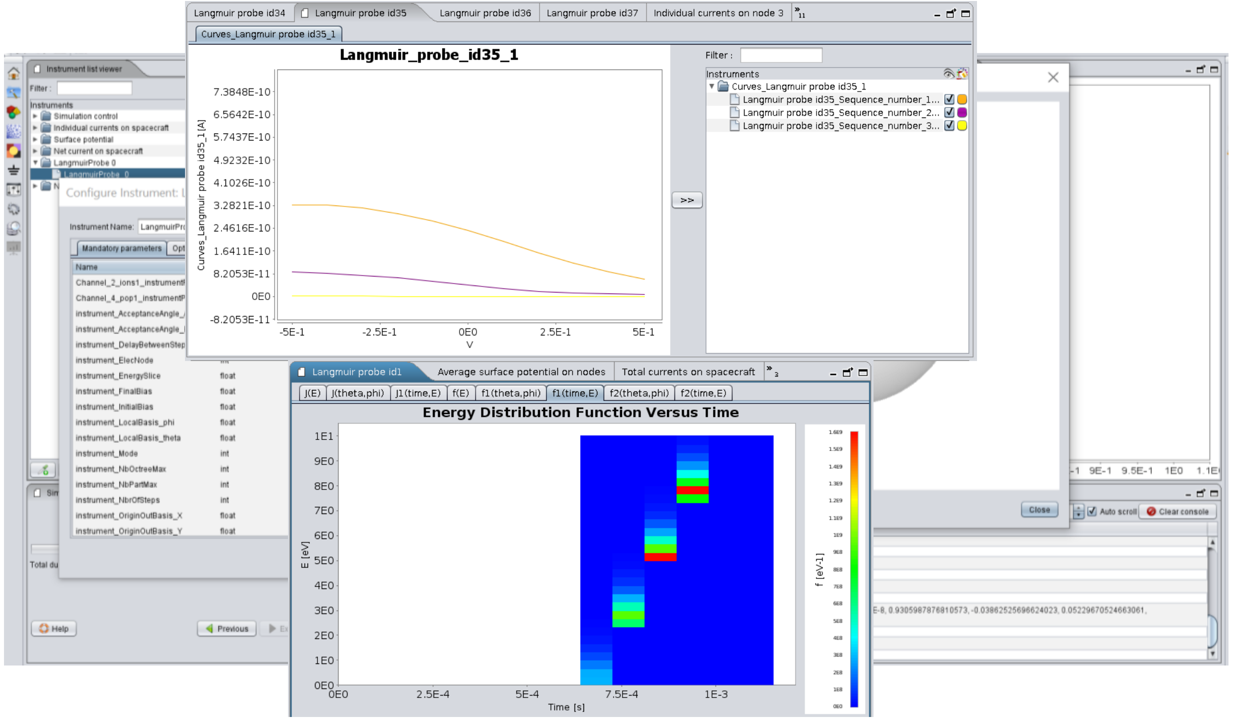
# Langmuir probe

- Single and multi-channel particle detector as a device
  - Single channel Langmuir probe by defaults
  - Easy to add channel
  - Improvement of IV Sweep
- Create a multichannel PD in the live monitoring
- Possibility to visualize the fields of view
- All the results for all individual channel + concatenated results for all the channels
- Possibility for advance user to add by default multichannel instrument in the SPIS catalog



# Conclusions

- Numbers of new developments and improvements coming from these projects:
  - Contributions proposed to be released in the 6.1.0 version (by July 2021 hopefully)
  - Add of unitary tests for new functionalities and for some older + 9 new verifications tests added
  - Non-Regression-Cases coming from previous project successfully passed
  - Validation campaign for the new developed functionalities performed in the two projects related

- Effort to merge into one User Manual
  - Advantages → all the information in one document / no more distributed in different documentation related to different projects
  - Drawback → huge document ! / for some cases the information are dispersed over the whole document / we try to reduce the length by suppressing deprecated functionalities (loss of information)

- Onera contributions to clean the code, memory usage and multi-threading management

- Most of the functionalities interoperate in SPIS but cross tests done on the most frequent or priority applications:
  - Too large field of application (GEO and LEO charging, EP, ESD, Dusts, Internal charging, scientific instruments, …) to have a complete matrix of tests
  - Need for contributions from the SPINE members and the SPIS user community to verify (feedback even with criticism are welcomed)
  - Hope for a new dynamic with the new website or other initiative to improve the contribution from community