Microscope plasma environment modelling

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THE FRENCH AEROSPACE LAB

return on innovation

Outline

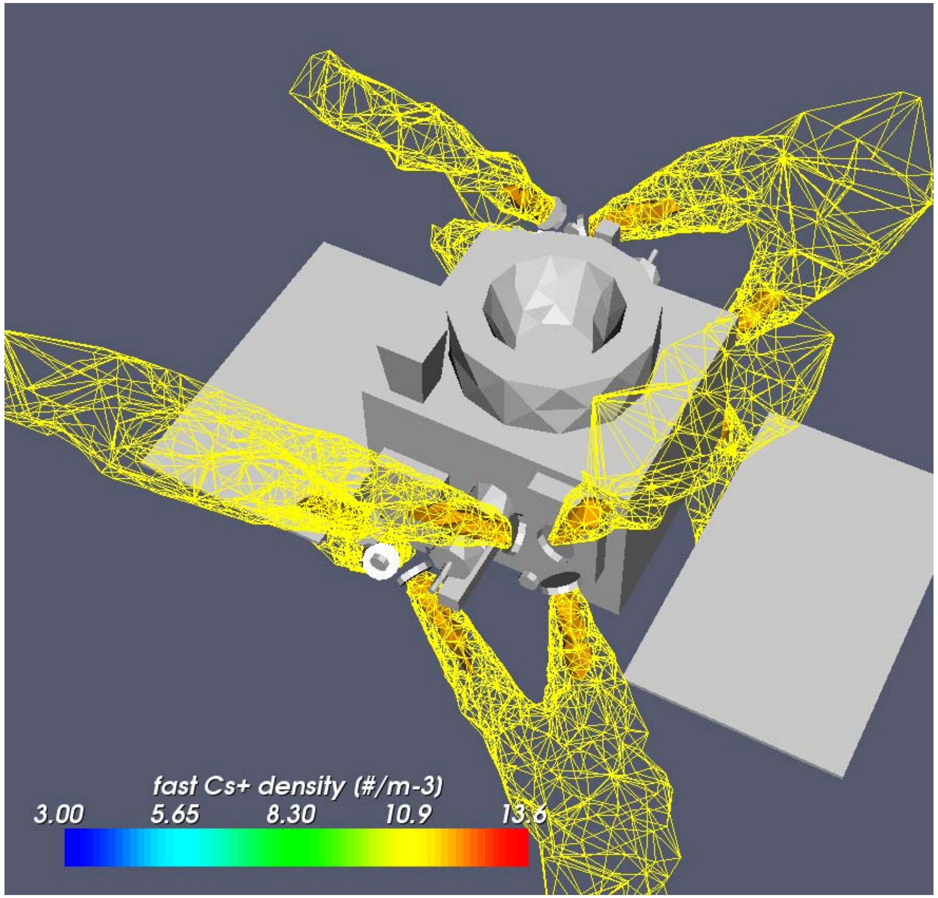
- FEEP plume modeling
  - Physics and numerical modeling
  - Numerical results
- Floating potential issues
  - Rationale
  - Strategies
  - Potential assessment

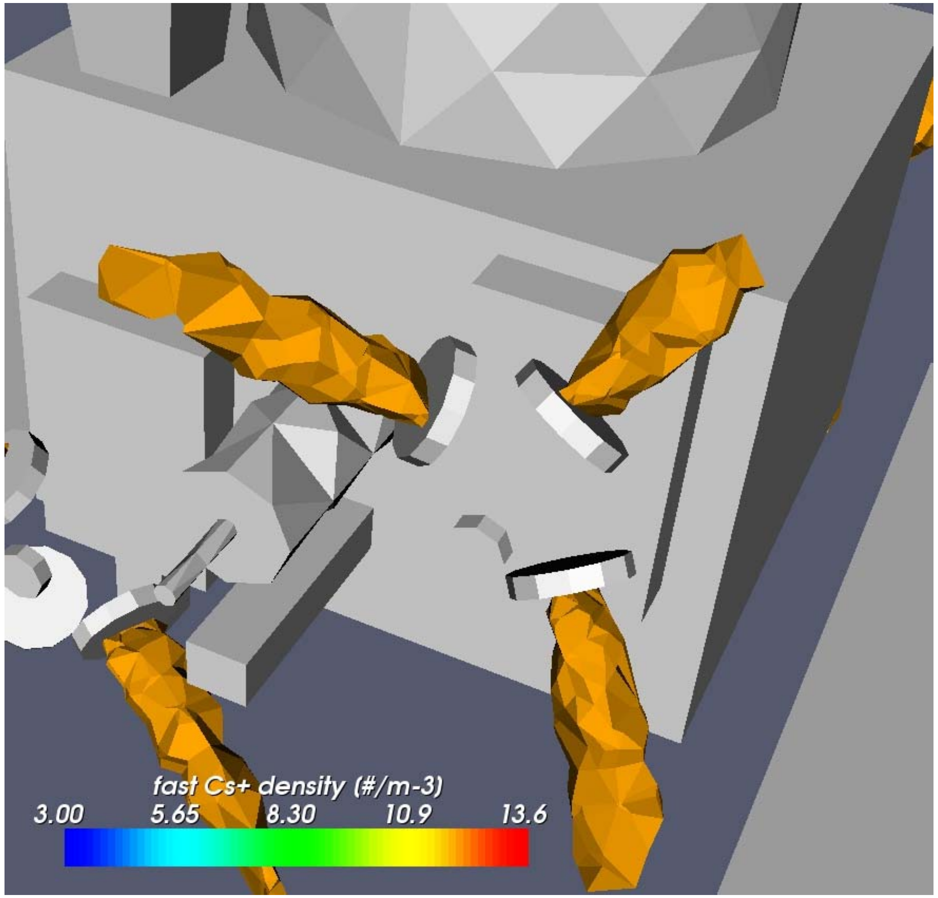
FEEP plume physics and numerical modeling

CNES R&T funding

- The physics
  - Charge EXchange between fast Cs+ ions and neutral Cs emitted by FEEP thrusters
  - Cesium is then thought to stick with probability close to 1
  - => effects on thermal absorptivity, emissivity, conductivity...
- Our global contamination model of Microscope SC (drag free mission to test equivalence principle):
  - FEEP plume:
    - Velocity distribution: data from Alta numerical model of FEEP exit slit
    - Current: in the modeling presented here 300 µA emitted by each FEEP
  - CEX:
    - Neutrals:
      - Flux : 20% neutral Cs, 80% Cs+
      - Distribution: Lambertian, integrated over all emitting surfaces
    - Cross section: energy dependant formula => 10^{-18} m^2 at 7-9 keV
  - Plasma:
    - PIC model of all ions (particle-In-Cell, kind of Monte Carlo): Cs+ fast/slow, ambient O+
    - Boltzmann equilibrium distribution for electrons

Fast Cs+ density

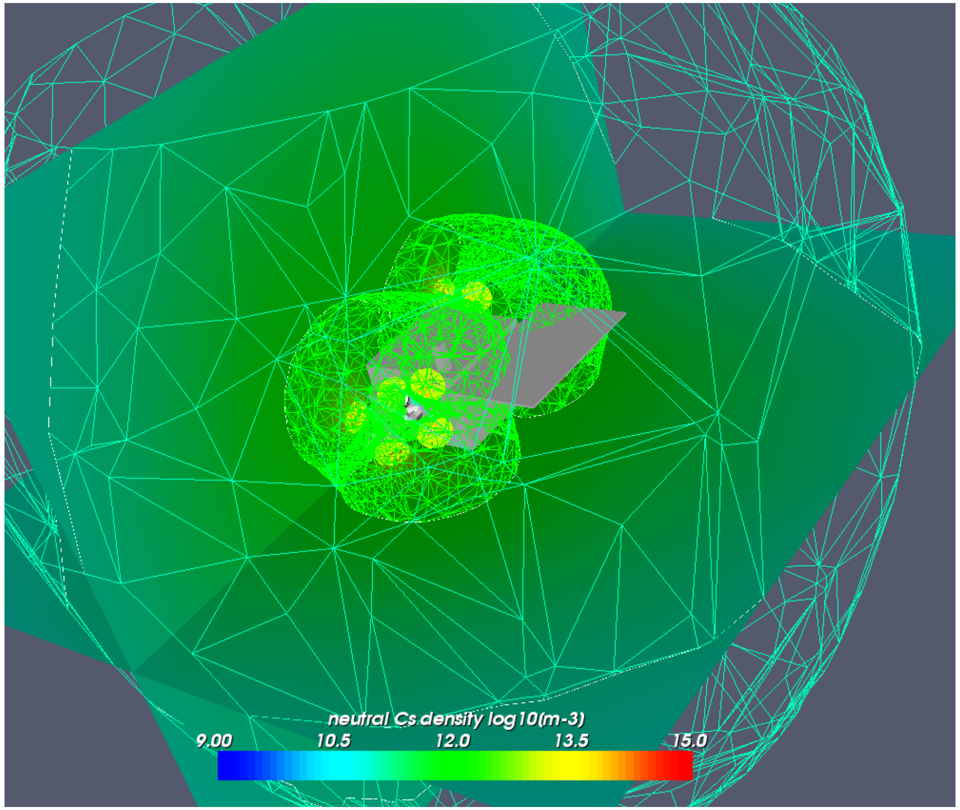


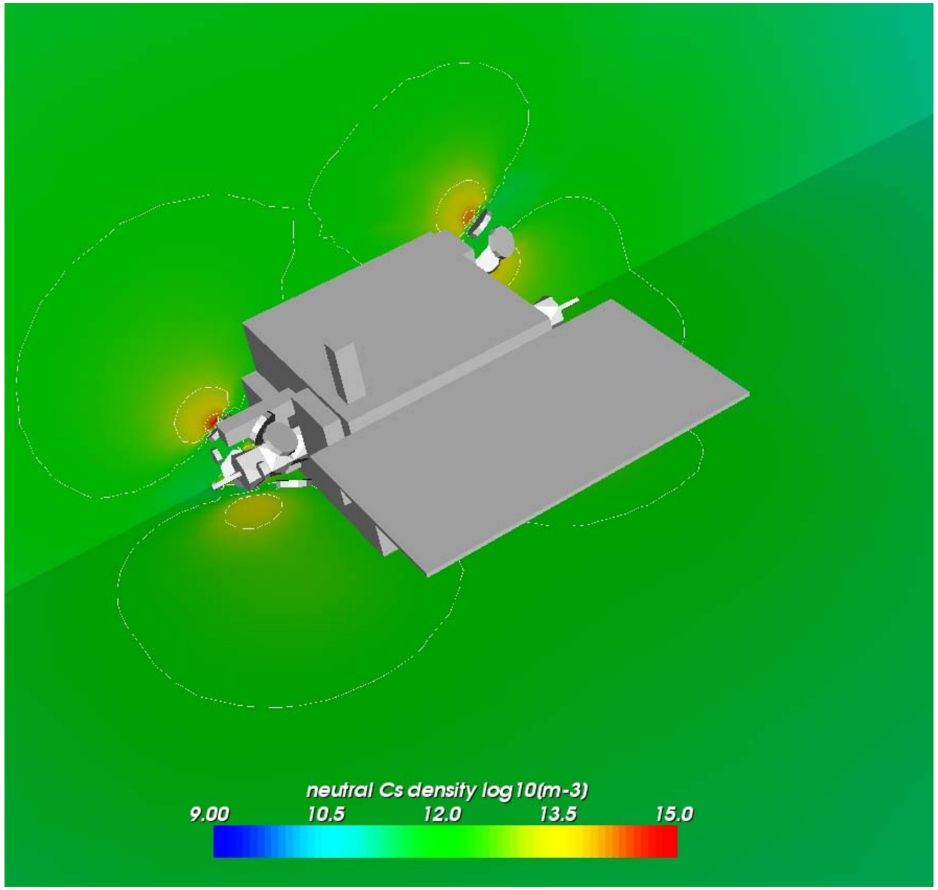


iso-contour surfaces, n = 10^{11} m^{-3} (yellow) and 10^{12} m^{-3} (orange)

NB: mesh refined locally close to FEEP nozzles

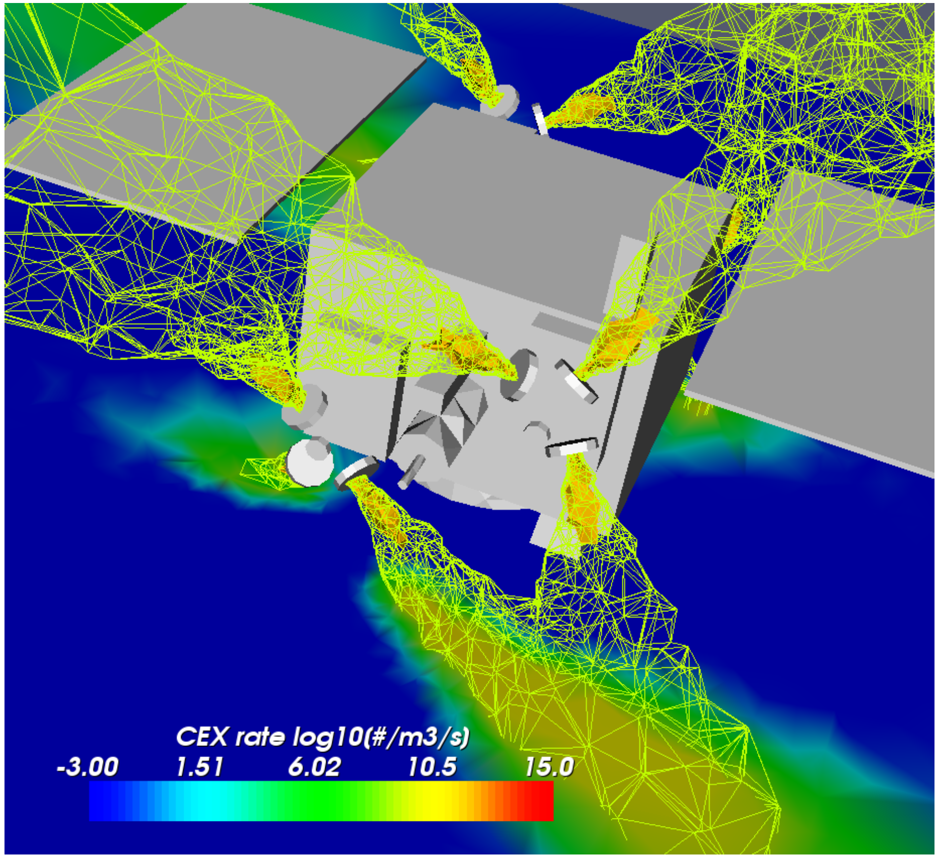
Neutral Cs density

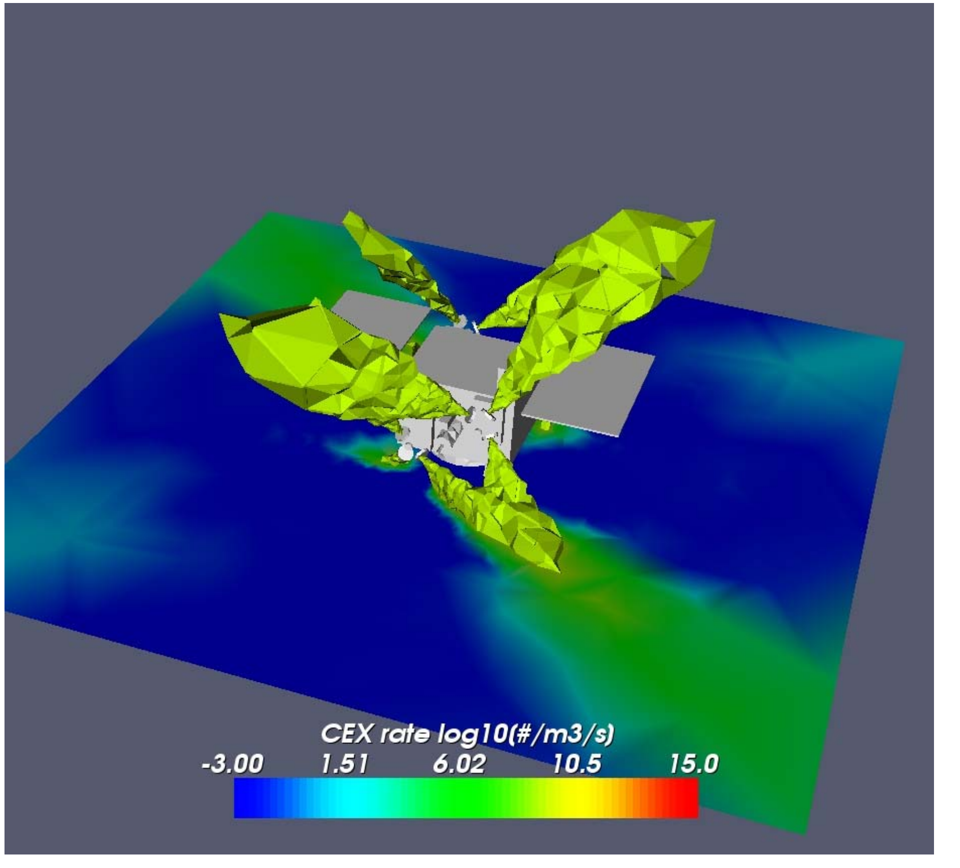




iso-contour surfaces, n = 10^{11}, 10^{12} and 10^{13} m^{-3}

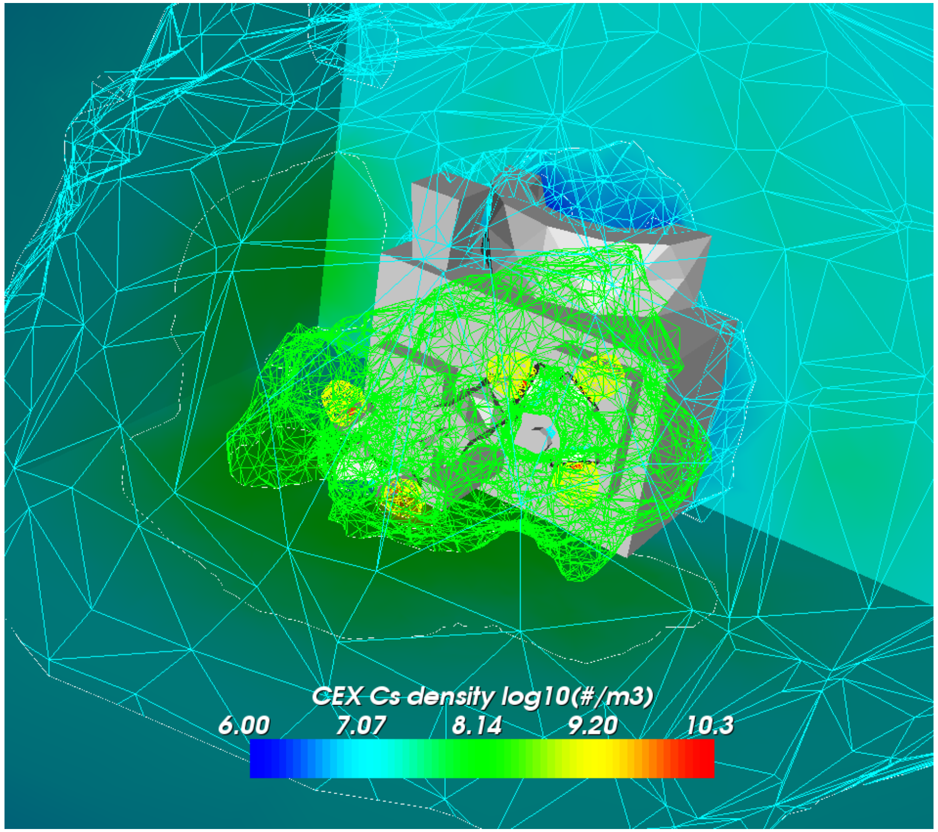
CEX reaction rate density

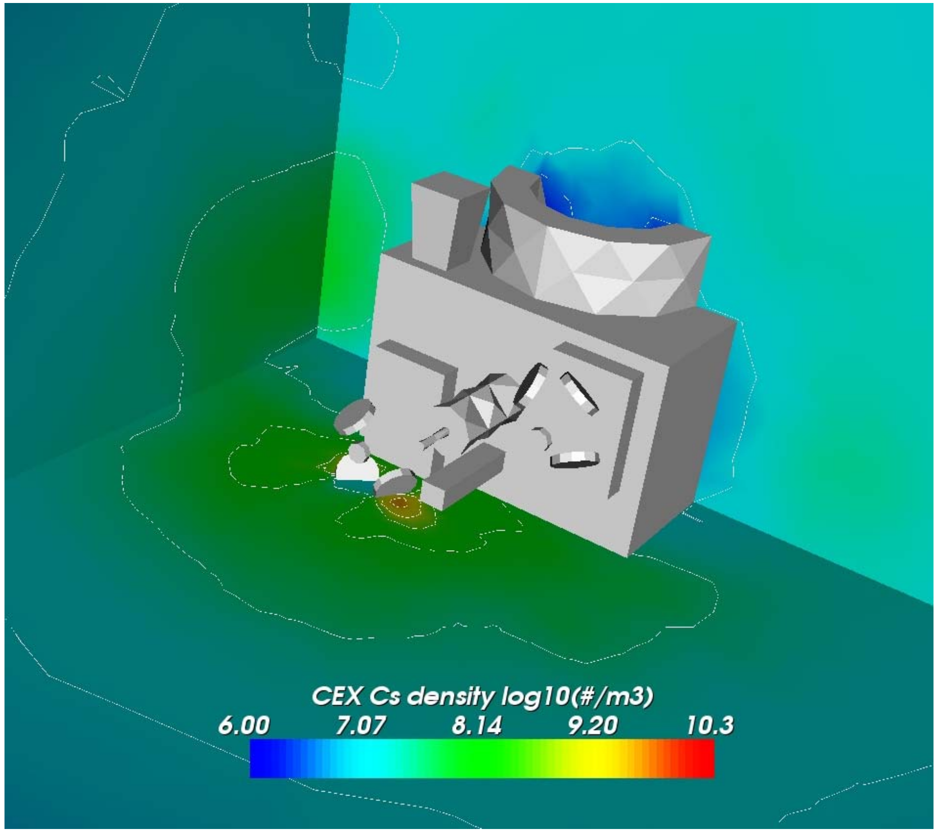




iso-surfaces 10^{9} and 10^{12} $m^{-3}s^{-1}$

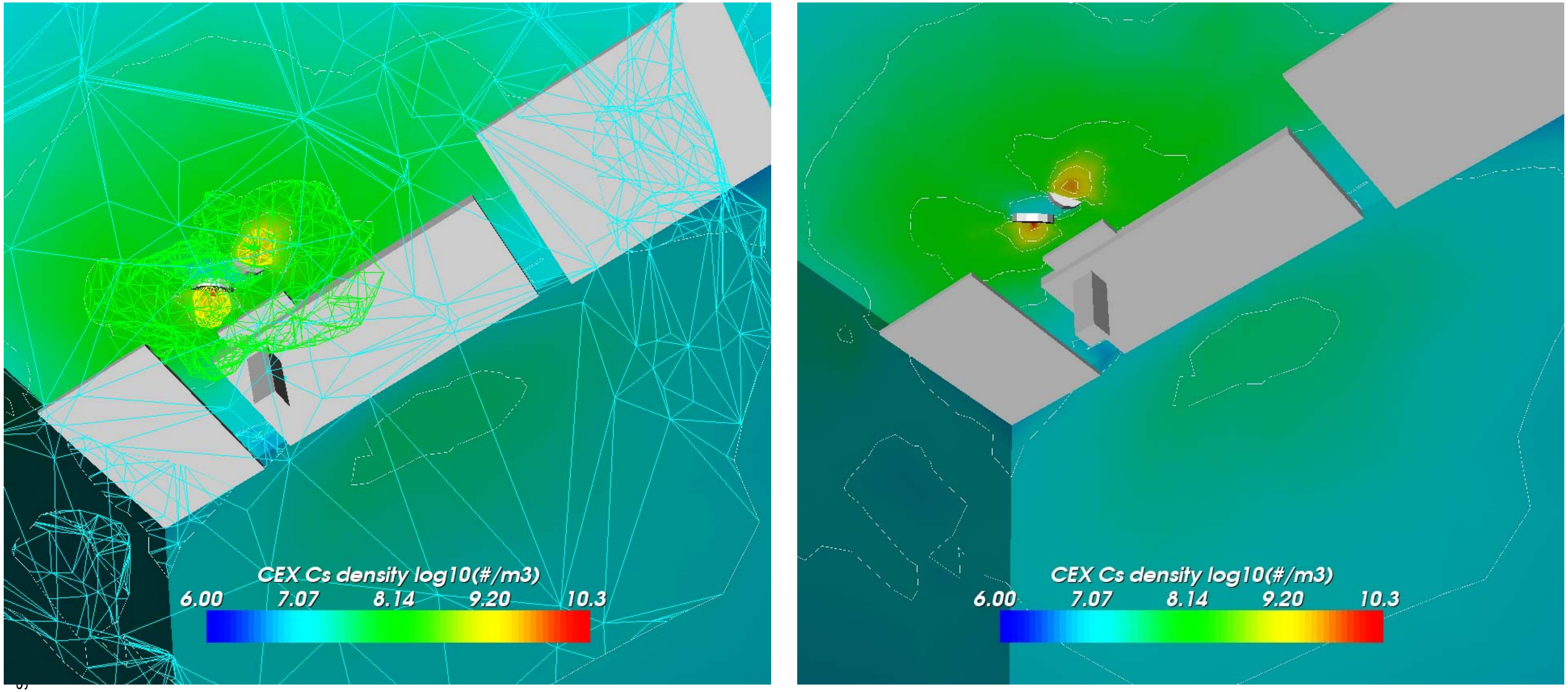
CEX Cs+ density





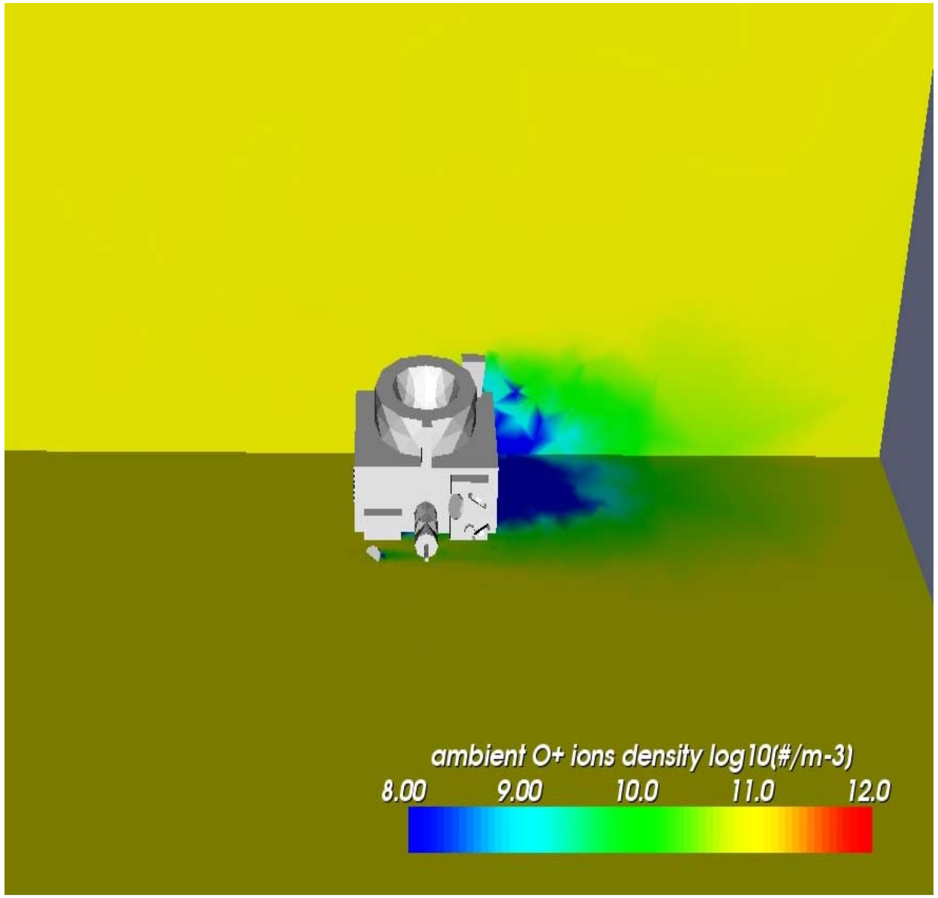
iso-surfaces $n = 10^7$, 10^8 and 10^9 m^{-3}

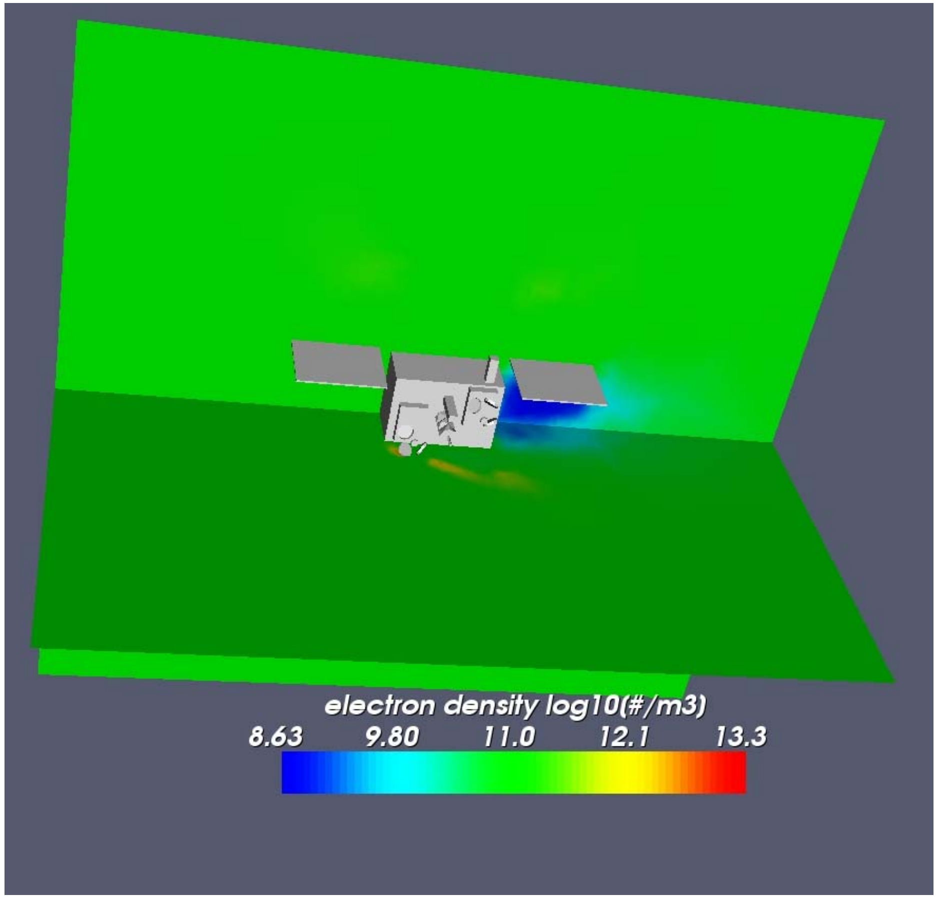
CEX Cs+ density



iso-surfaces n = 10^7, 10^8 and 10^9 m^{-3}

Ambient densities

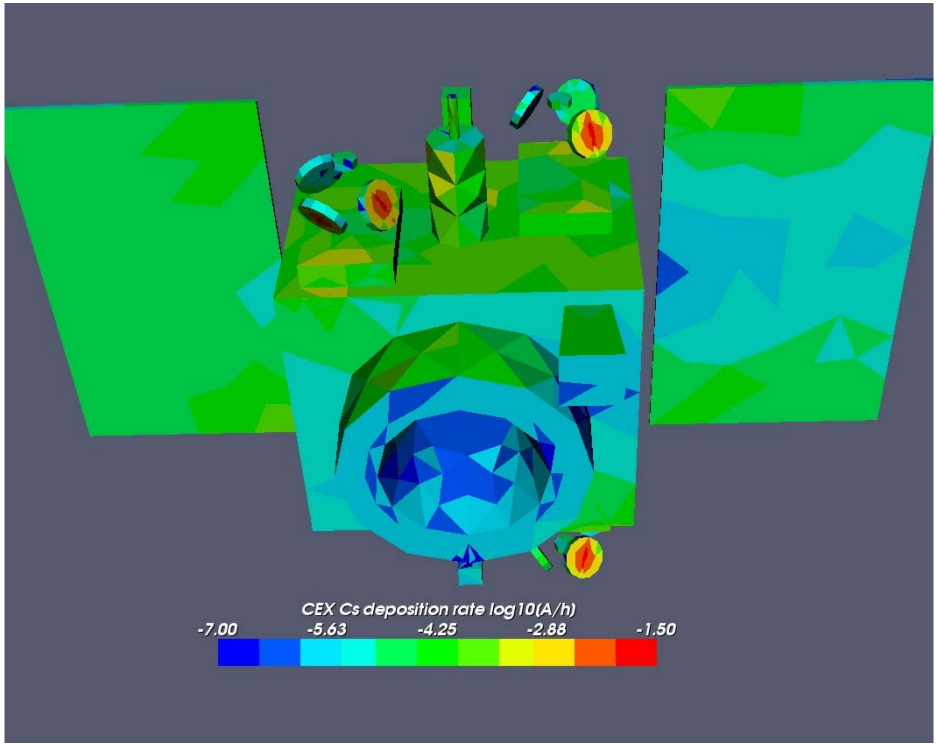


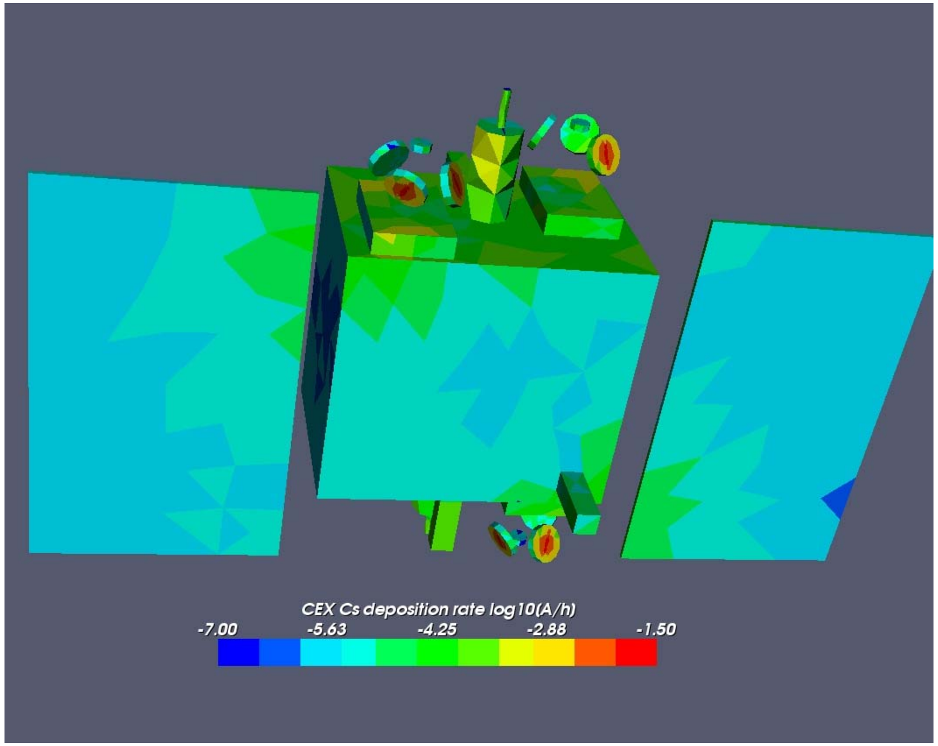


O^+ ions: wake depletion

Electrons: wake depletion + neutralisation of Cs^+ in plumes

CEX Cs+ deposition rate





Maximum (red) = 0.03 Å/h

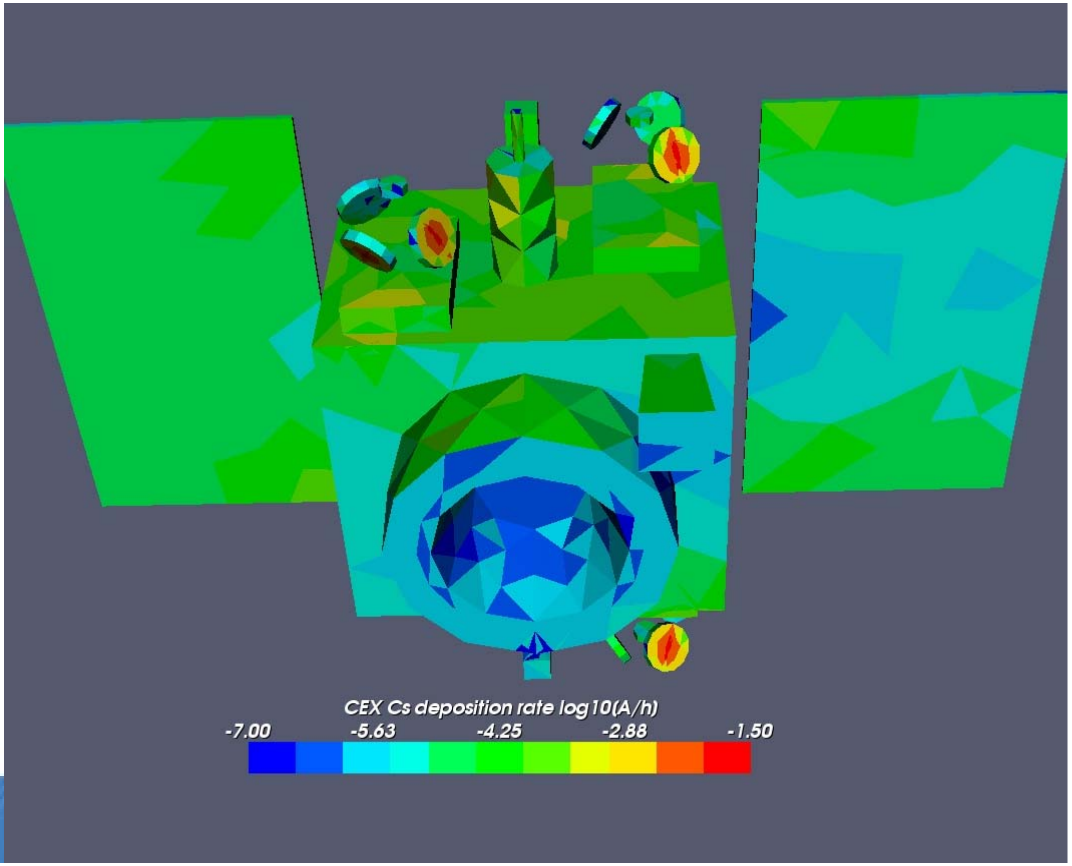
Green ~ 0.0001 Å/h

Integrated deposits

- Typical parameters
  - Duration: let's go for 1 year: × **8760 H**
  - Average Cs+ flux ratio ~ 100 µA : × 100 µA / 300 µA = **1/3**
  - Average Cs flux: **1/3** also if proportional to Cs+ ?
  - => overall factor ~ 1000 to transform [Å/h] into [Å /yr]

- => deposits in the range
  - 10 Å/yr near FEEPs (few cms)
  - 1 Å/yr on FEEP's face
  - up to 1 Å/yr on PVSA

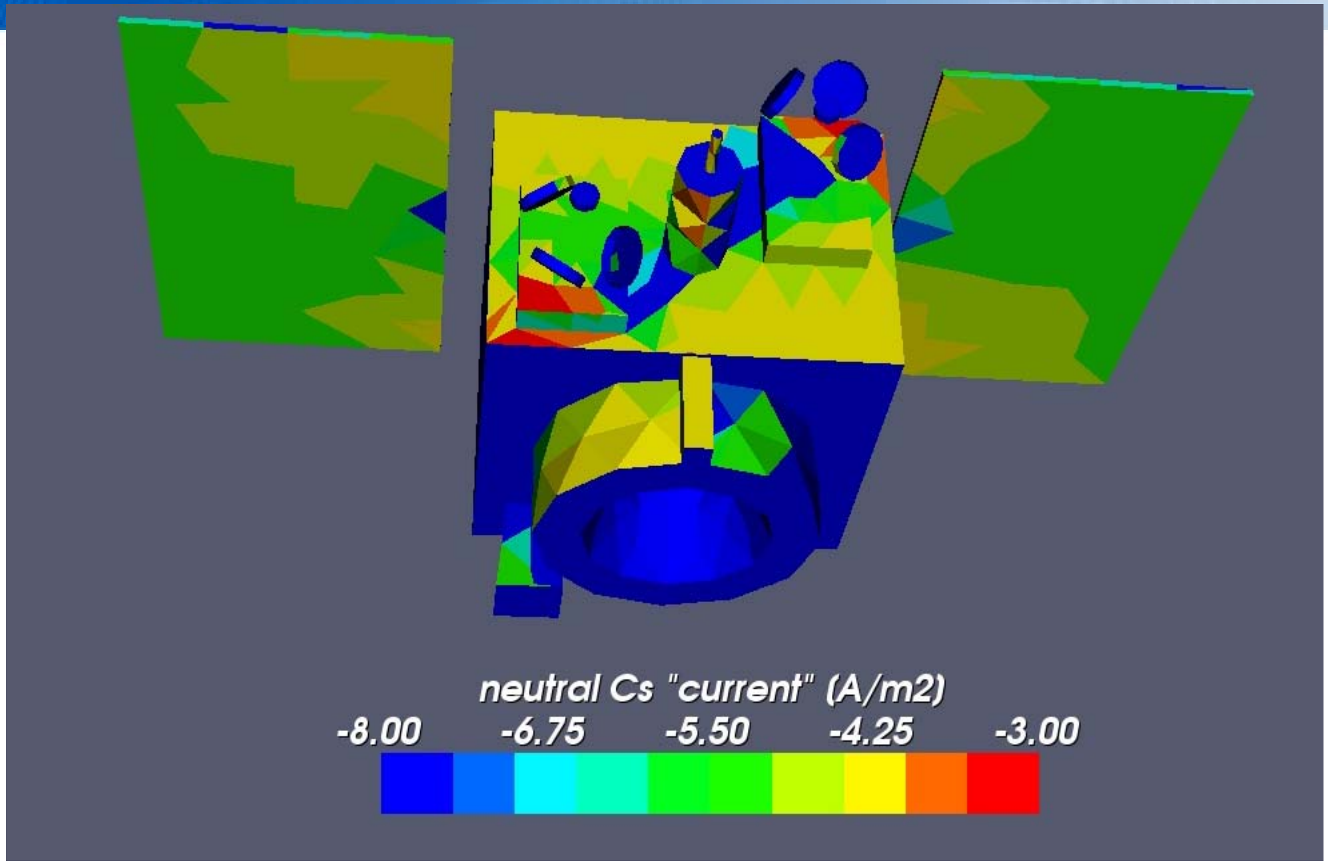
- Uncertainties
  - Neutral efflux
  - Modelling ?



Other contamination processes

- Molecular processes:
  - Direct fast Cs+ impingement: spacecraft designed to avoid it
  - Direct neutral Cs flux: see next slide
- Droplets:
  - Emission, charging, plume pressure, evaporation, sputtering
  - Currently under study, need of experimental characterization

Neutral Cs direct flux



- Scaling to Å/yr:
  - 1/e × at_mass / density × Å _in_a_m × sec_in _a_year
  - 1/1.6 10^{-19} C × 2.2 10^{-25} kg/# / 2000 kg/m^3 × 10^{10} Å/m × 3 10^7 s/yr = factor 2 10^5
  - Values green to red, in the 10^{-6} to 10^{-3} A/m^2 range => 0.2 to 200 Å/yr range
- Comparable to deposition rate from CEX Cs+

Conclusion on contamination

- Levels of Cs contamination predicted:
  - Rather small
  - But could be enough for damage (large effects)
  - Need to improve our confidence in these numbers (experiments...)

- Other mechanisms still to be assessed (R&T starting): droplets

- Effects studied in parallel (other CNES R&T)
  - Deposit => optical / thermo-optical properties
  - Metallic deposit => much larger effect than organics (for similar thickness)
  - Chemical reactions (fluoropolymers...): very important!
  - May be reduced by evaporation (not after chemical reactions!)

Electrical concerns

- Two different concerns

1. Neutralisation of Cs+ ion space charge
   - Density a little above ambient: ~ 10e13 m^{-3} maximum versus ~ 10e11 m^{-3} ambient
   - ⇒ Can be neutralised by ambient electrons quite easily
   - ⇒ Not a real concern

2. Floating potential:
   - Emission of several mA of fast Cs^{+}
   - To be compensated by ambient ion collection
   - ⇒ Not enough in most situations
   - ⇒ Need of electron emission (neutraliser)
   - Study reported here

Floating Potential Assessment

- Without neutralisation (no electron emission to compensate for Cs^+ emission):
  - Catastrophic:
    - Very quick absolute negative charging:
      $dV/dt \sim Ics+/Cabs \sim I/(\varepsilon_0 S/\lambda_D) \sim -10^{-3} / (10^{-11}\ 3 / 10^{-2}) \sim -3.10^5$ V/s
    - Quick relative charging on coatings:
      $dV/dt \sim (Ienv/S) / (Ccoat/S) \sim env_{ions}/(\varepsilon_0\varepsilon_r/d) \sim (10^{-19}\ 10^{11}\ 7500) / (10^{-11}\ 3 / 10^{-4}) \sim 300$ V/s
    - => major ESD issue
    - => FEEPs to be stopped immediately in case of neutraliser failure (within ms to second)
  - Nothing more to study: to be avoided absolutely !
- With neutralisation:
  - May float positively
  - Numerical (3D) approach difficult (small Debye length => only realistic approach when electron density can be described by Boltzmann law => implicit solver makes simulation stable even for cells larger than λ_D)
  - Here: Analytic approach (simplified models)

Analytic collection model

- Analytic collection law for all components
  - Emitted Cs+ (by FEEPs)
  - Emitted e- (by neutralisers, Alta S.p.A.)
  - Collected from environment:
    - e- by spacecraft (Langmuir-Blodgett)
    - e- by anode (“)
    - O+ by spacecraft (interception)
- Total current computed
- Floating potential condition: $I_{tot} = 0$

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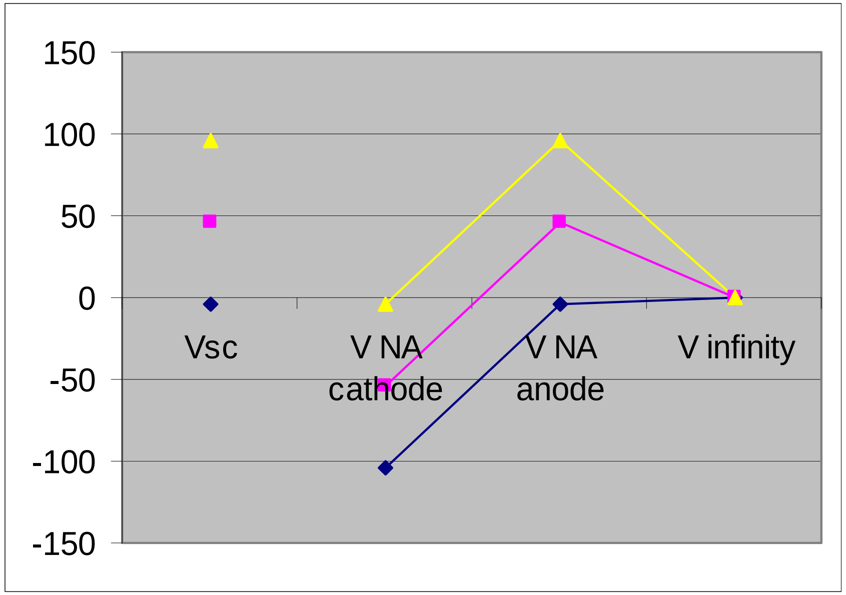
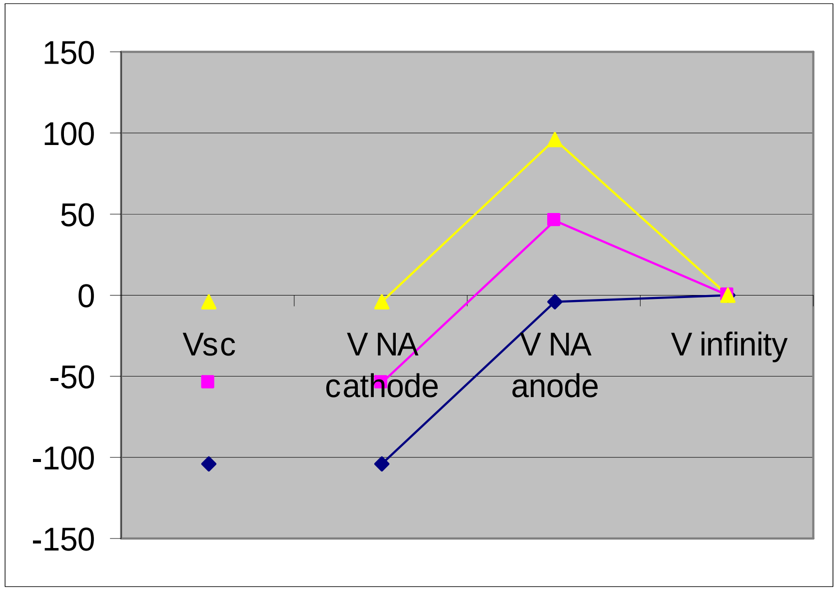
Two SC grounding options





1. **SC grounded to anode** ("Accel-accel")
   - If NA dominates environment and works properly: SC quite positive
   - Bad

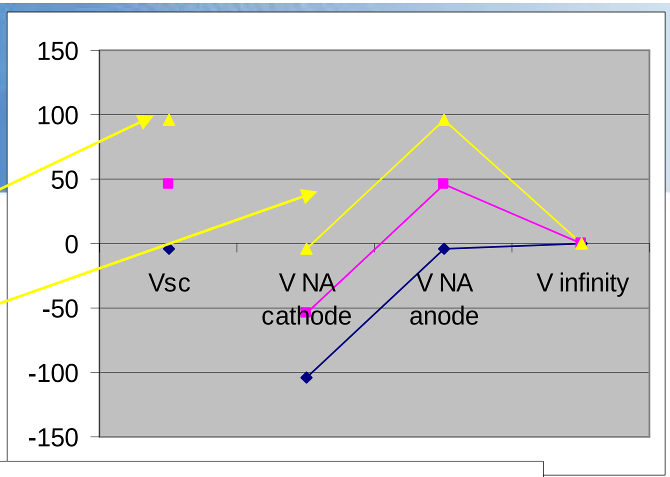
2. **SC grounded to cathode** ("Accel-decel"):
   - If NA dominates environment and works properly: SC "slightly" negative
   - Good

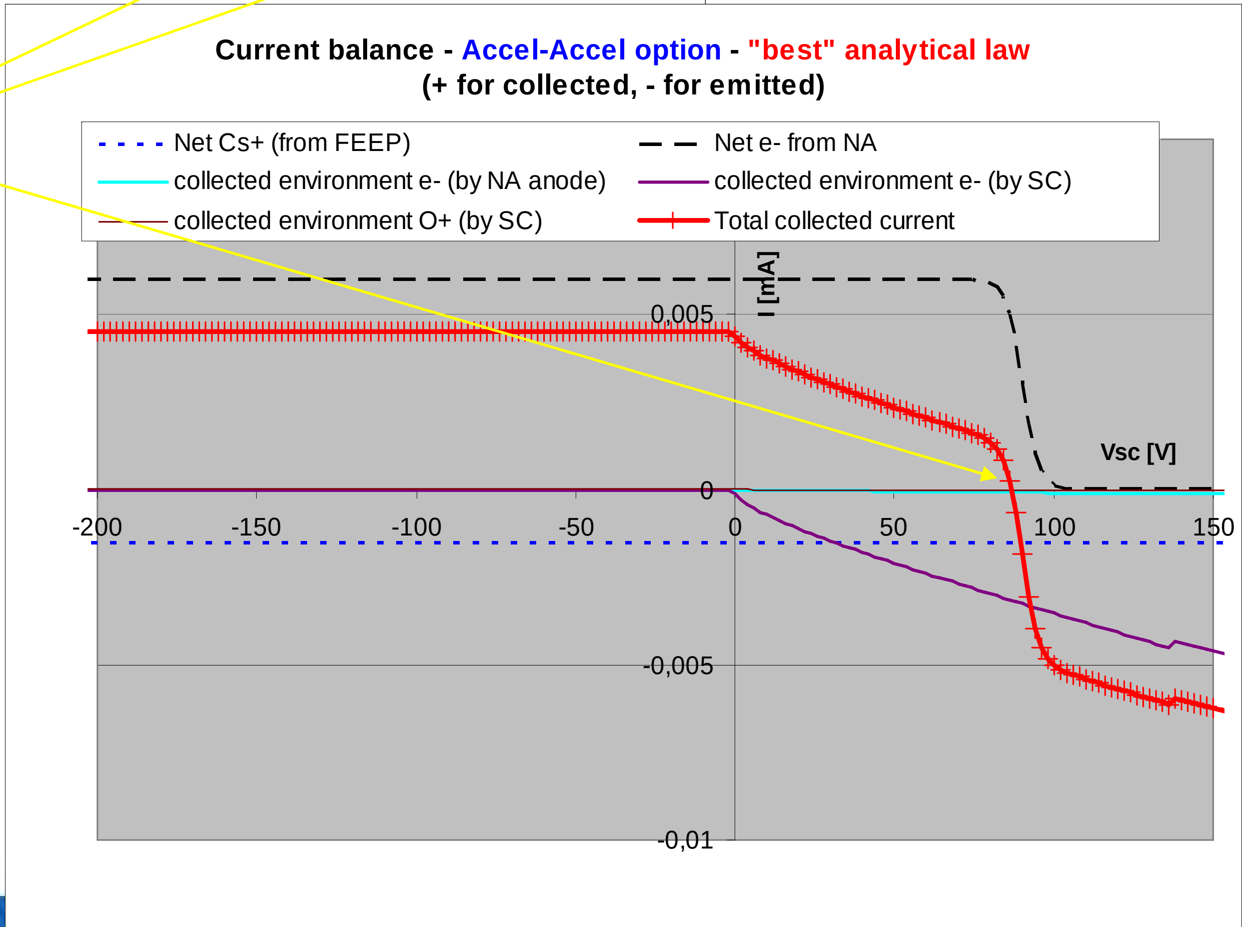
- ✓ Emits electrons in excess
- ✓ Recollects the extra e- at the price of small variations of $V_{cathode}$

1. Anode grounding option

- **If FEEP + NA dominate environment ($n = 10^4\ cm^{-3}$):**

=> (very) positive potential





- Environment may also dominate ($n = 10^5\ cm^{-3}$):

=> floats close to 0

1. Anode grounding option

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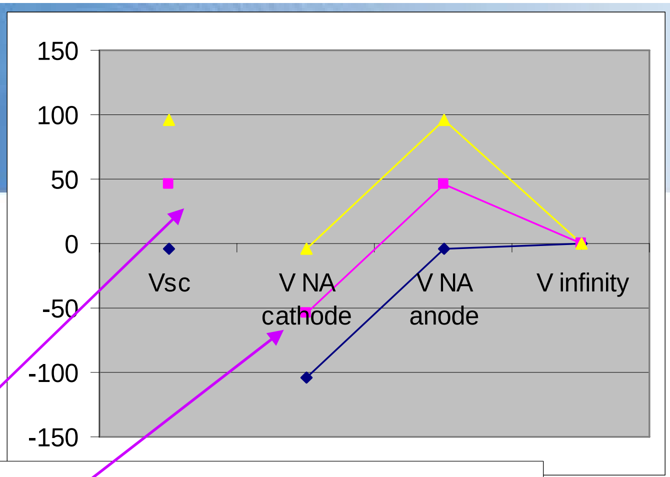
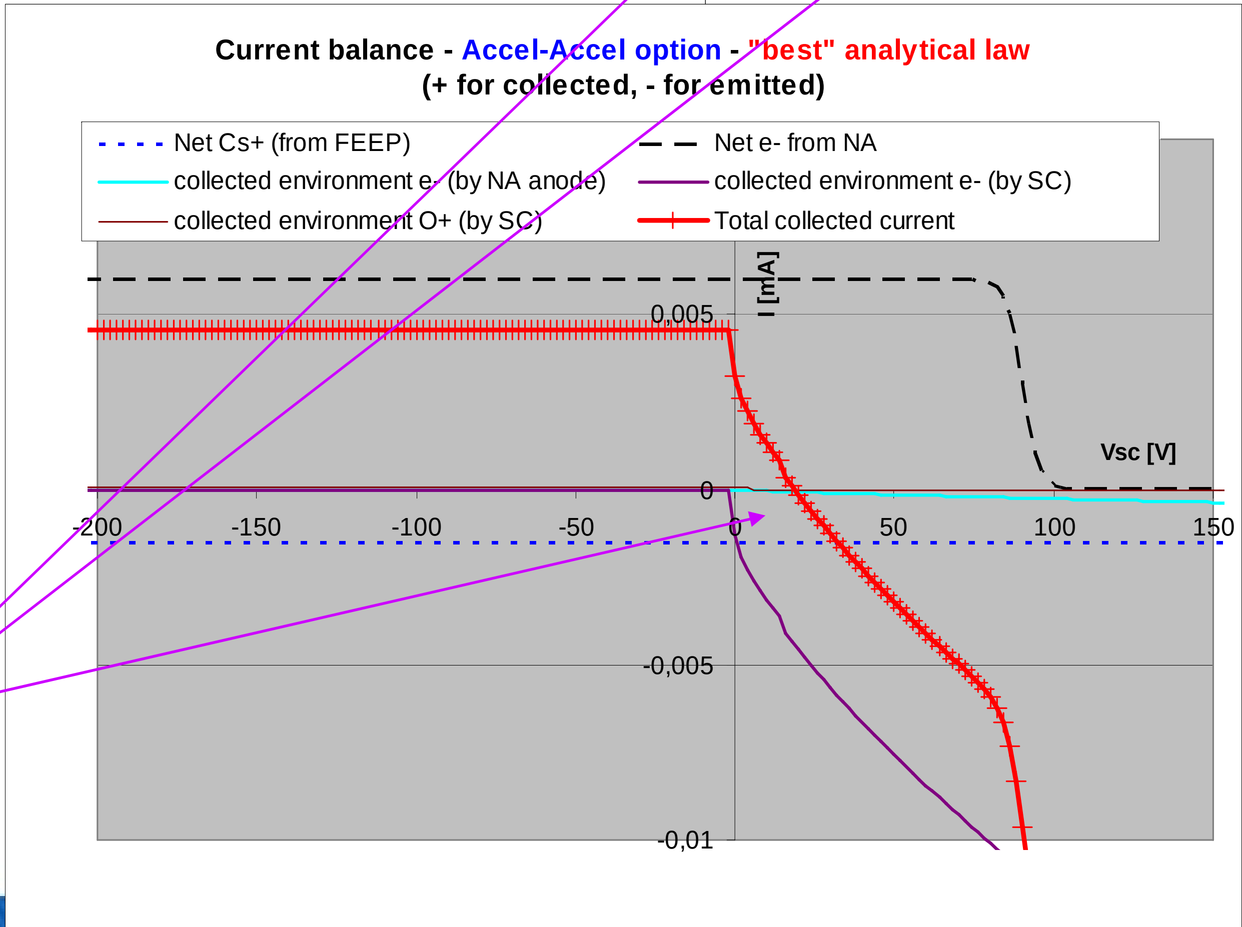
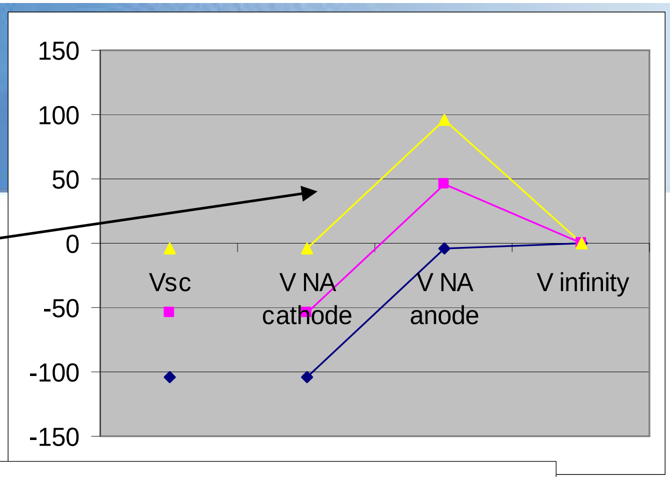




- **Environment may also dominate ($n = 10^5\ cm^{-3}$):**

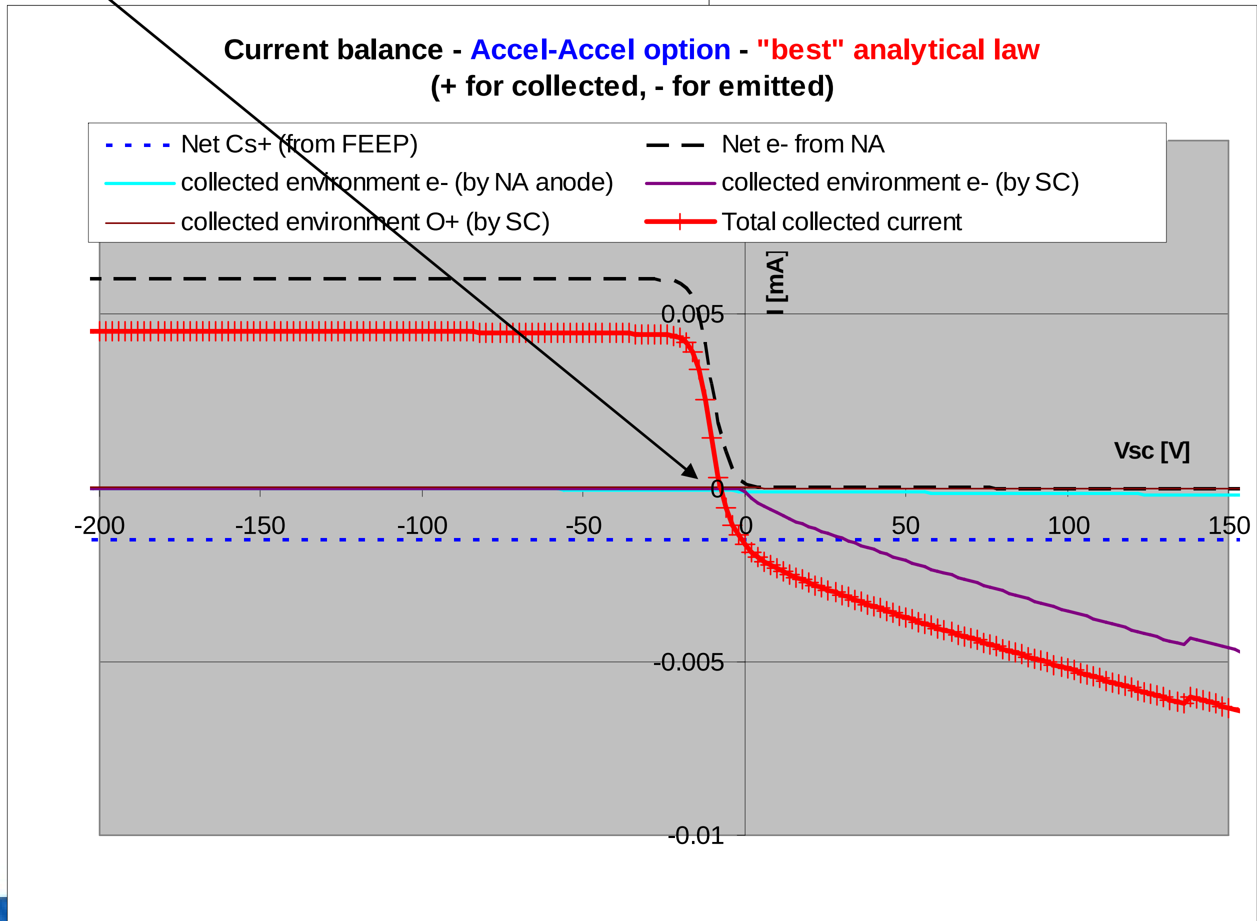
=> floats close to 0

2. Cathode grounding option



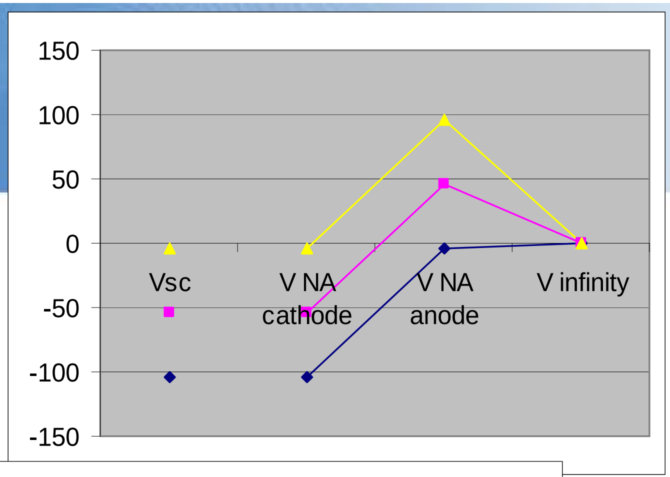
- **Negative potential**

=> FEEP + NA dominate environment



- Sensitivity to NA I-V characteristics

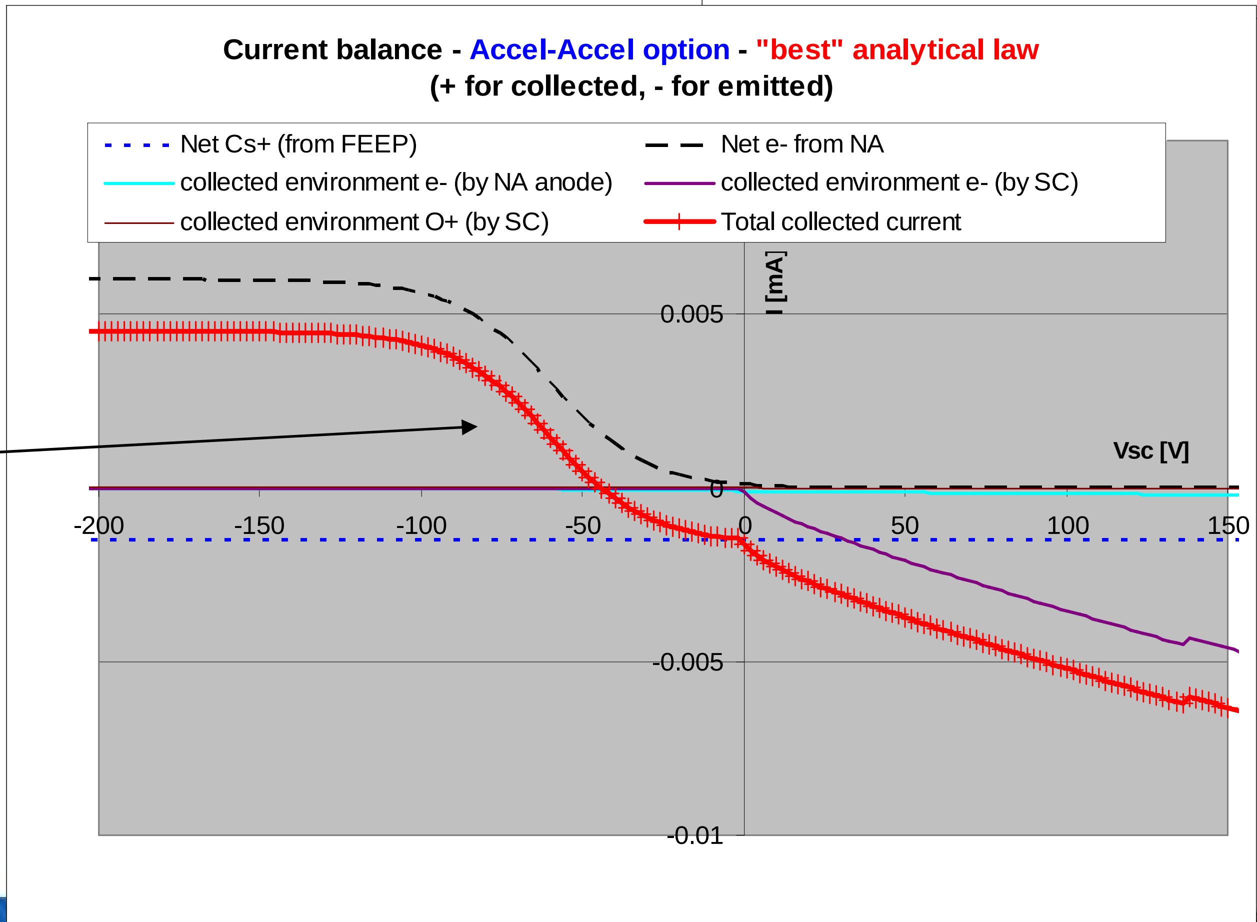
2. Cathode grounding option



- Negative potential

=> FEEP + NA dominate environment

- **Sensitivity to NA I-V characteristics**



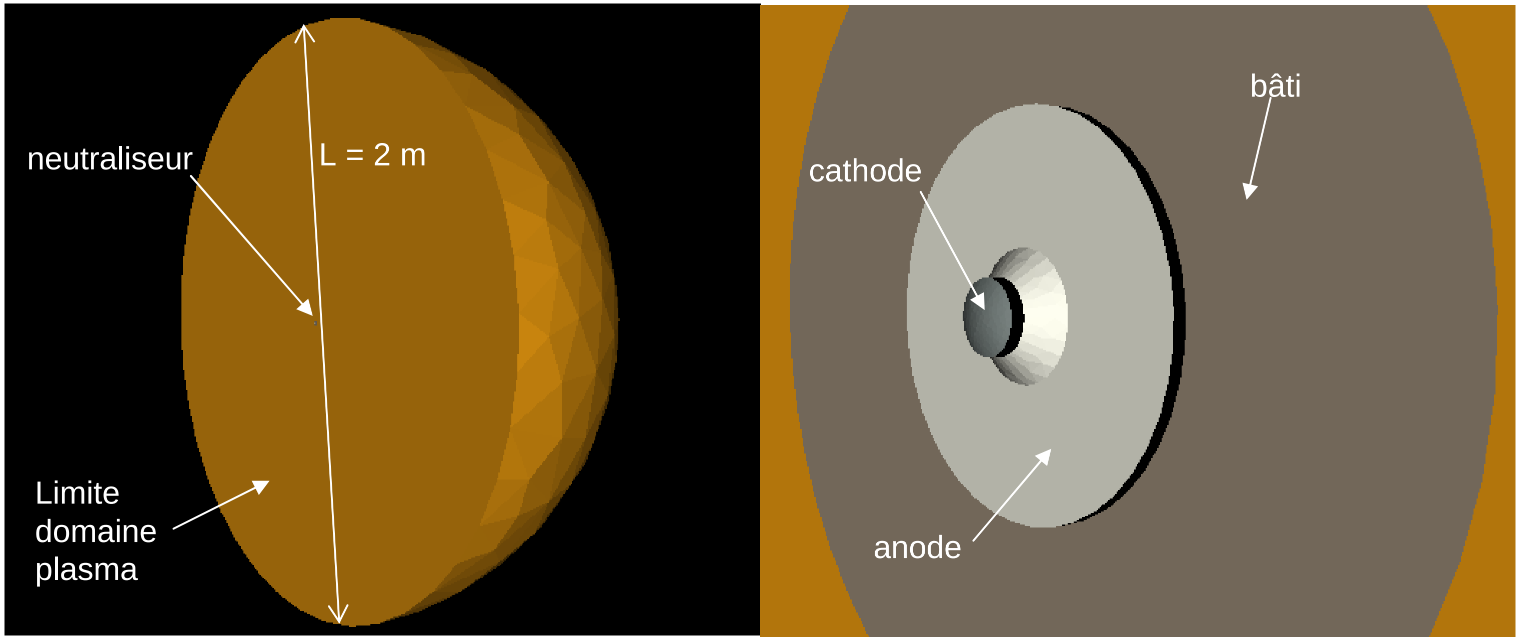
Conclusions / discussions on neutralisation

- Neutraliser needed better characterisation => CNES R&T :
  - Experiment in plasma tank
  - numerical simulation of NA with SPIS
- Two possible approaches for global current balance:
  - Get I-V characteristics for each component (including SC) => find *I*=0 "in Excel"
  - Make a system level simulation (SPIS) including the I-V characteristics of the NA
- Result overview :
  - I-V exhibits a rather large transition region => should float significantly negative
  - I-V is somewhat sensitive to plasma density => some fluctuations of Vsat
  - Compliant with specifications yet

Background Material

Domaine de calcul

- Domaine de calcul étendu sur un rayon de 1 m
- Tailles caractéristiques de la cathode et de l'anode : 2 et 20 mm



DESP – 10th SCTC

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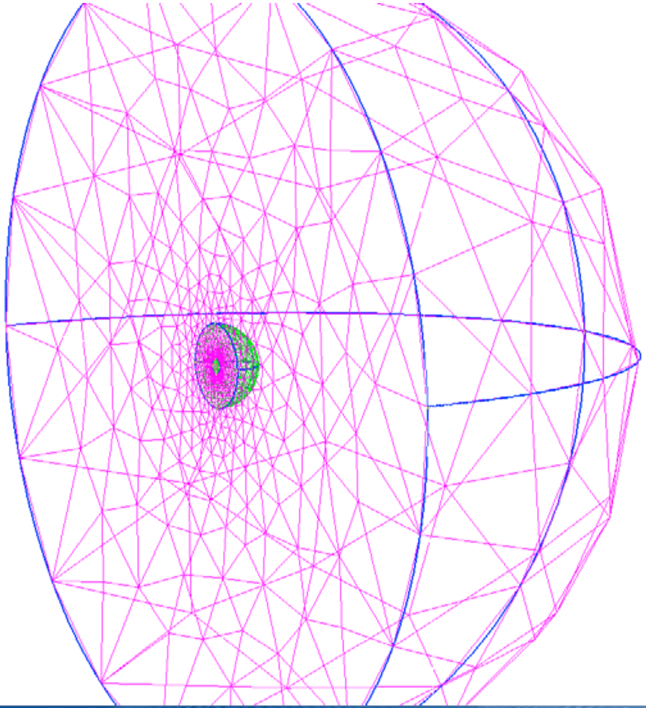
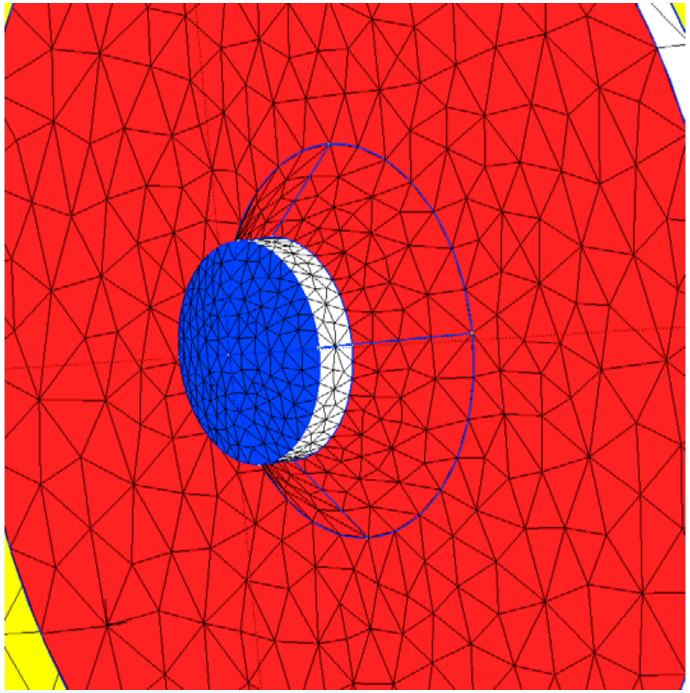
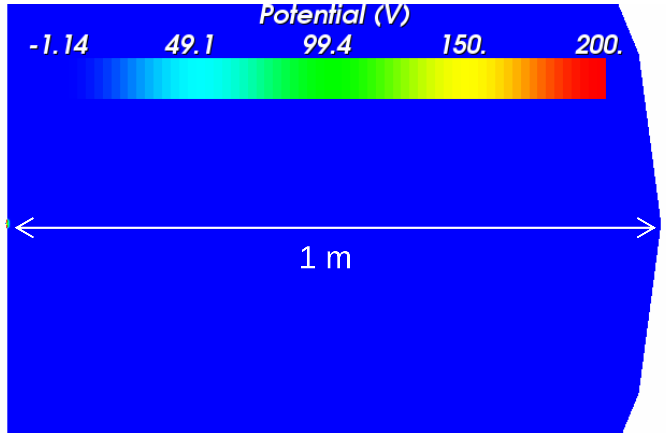
Maillage

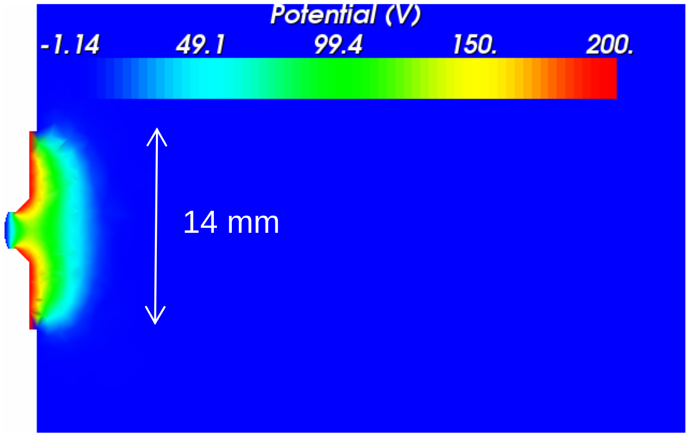
- Maillage raffiné autour du neutraliseur (200 µm à la cathode)
- Relâché aux limites du domaine de calcul
- Boîtes imbriquées pour gérer un raffinement progressif
- 50 000 tétraèdres

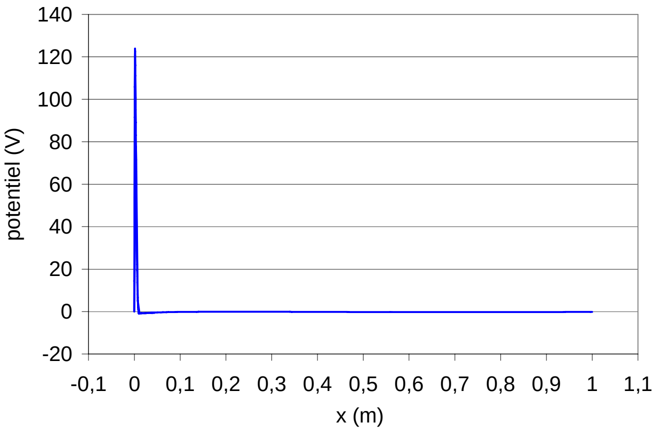


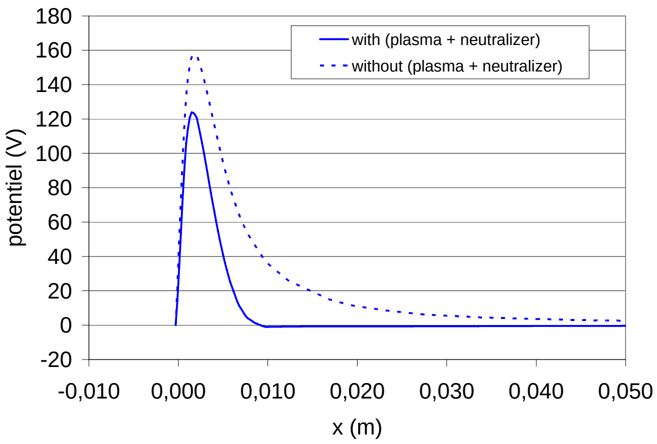


Cas nominal V_{cath} = 0 V - Potentiel

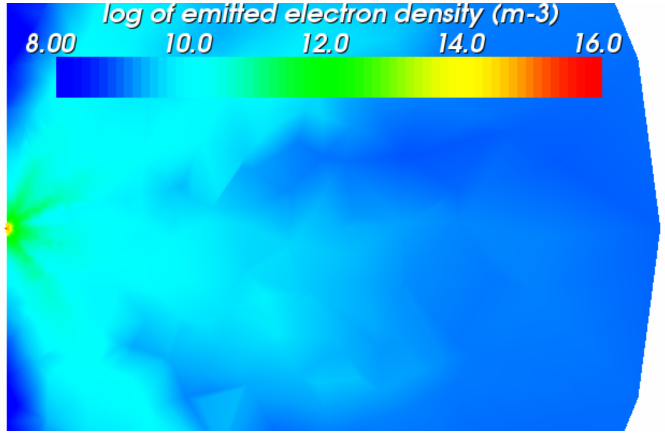


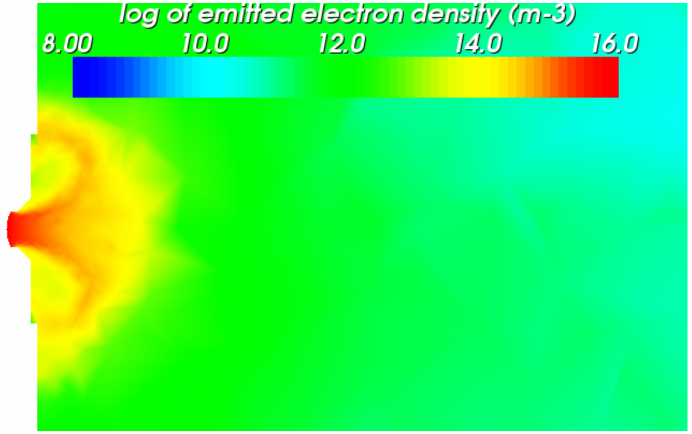


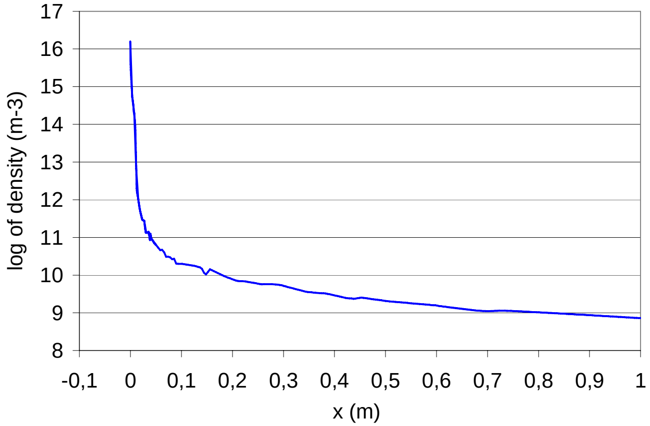


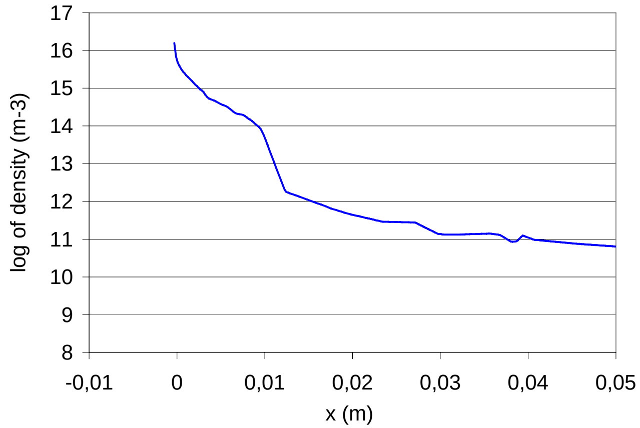


Cas nominal V_{cath} = 0 V - Electrons émis









Cas nominal – Caractéristique IV