Simulations of plasma thruster and large antenna effects on the electrostatic behavior of spacecraft in GEO

SCTC 2016, April 4-8, 2016, Noordwijk, The Netherlands

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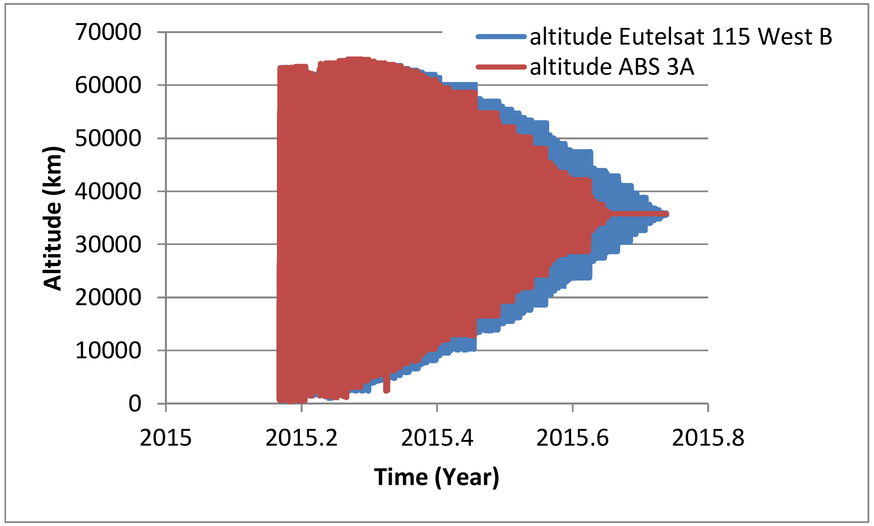
Introduction

- Context : All electric orbit transfer of GEO SC

- Analysis of risks during the orbit transfer
  - Plume interaction with spacecraft
    - Plasma induced discharge
    - Solar arrays power losses
    - Spacecraft erosion and contamination
  - Radiation induced effects
  - Charging effects LEO/MEO/GEO plasmas



- Analysis of the electrostatic risks at GEO (after OT phase)
  - Change of material properties in surface due to contamination, erosion, redeposition

Plume and spacecraft charging during EOR

Erosion during EOR

Charging at GEO after EOR
Large antenna reflectors effects

Summary

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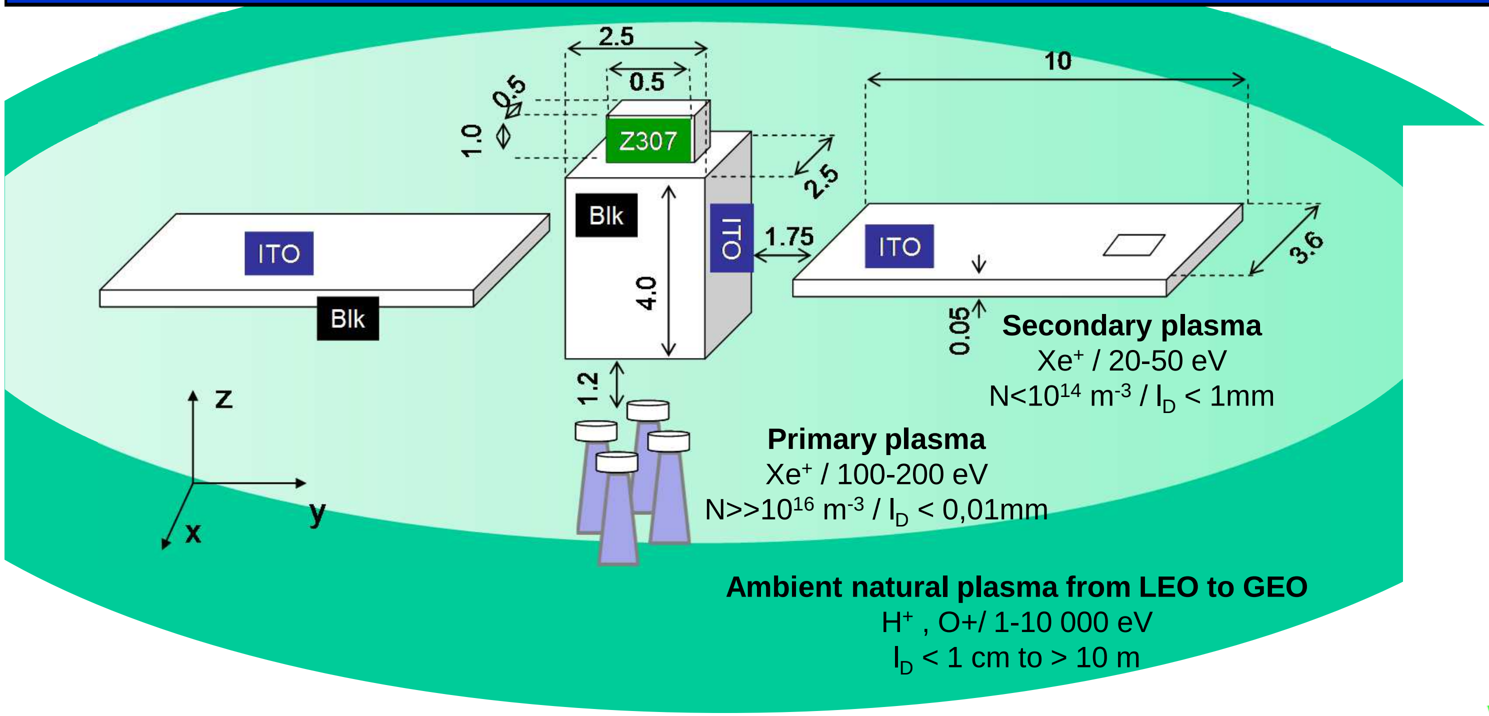
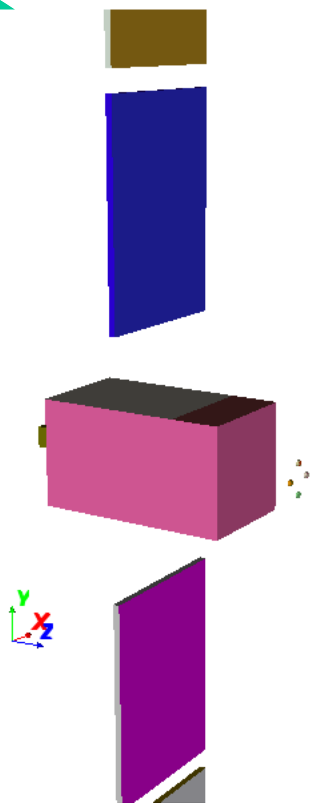
Plasma plume interaction with spacecraft





Spacecraft
- Solar arrays constant orientation towards the Sun (+Z)
- Body and thrusters rotation around (Y)

Thrusters
- Option A : 4 low-power thrusters (SPT 100 type)
- Option B : 1 high power thruster (SPT 140 type)
- Fast ions beam energy = 150 eV, current 20 A

Secondary plasma
- Charge exchange reaction assuming 5 % neutrals

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Challenge : Perform large 3D simulations

- Full PIC computation is prohibited
  - Debye length λ_D~10 µm at thruster exit → computational volume $L^3 > (10^6\ \lambda_D)^3$
  - Duration of 1 s for spacecraft charging and neutral dynamics > $10^{11}\ \omega_{pe}$

- Some lessons learnt from previous works dealing with 2D plume simulations
  - Hu et Wang 2015
    - Full PIC showed different electron cooling behaviours in 3 regions
      1. thruster exit (r<1 cm): polytropic law (electron cooling)
      2. dense plume (r<1-10 m): isothermal due to potential well (yet anisotropic !)
      3. transition to ambient plasma: another but yet undefined polytropic law

  - Lopez Ortega, Katz and al. 2015
    - Non negligible effect (10%) of electron-neutral ionization in the plume
    - Need to model CEX by PIC to correctly compute the backflow to spacecraft

  - etc…

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Our current approach

- SPIS 5.1.8 intermediate approach
- 3d unstructured mesh : 1 - 50 cm refinement
- PIC for fast and CEX ions (no electron-neutral ionization)
- Analytical Maxwell-Boltzmann electron distribution
  - Tuned to fit region 2 extending up to the external boundary in the present work
  - Ambient plasma (LEO / MEO) with protons at 3 eV / 10^9 m^{-3}, neutralized by the same population as for the thruster
  - Provide rough estimates of plume and spacecraft charging, sufficient for basic analysis of erosion and contamination
- CPU time reduction
  - Implicit solver for the non-linear Poisson equation
  - Time integration scheme to speed computations

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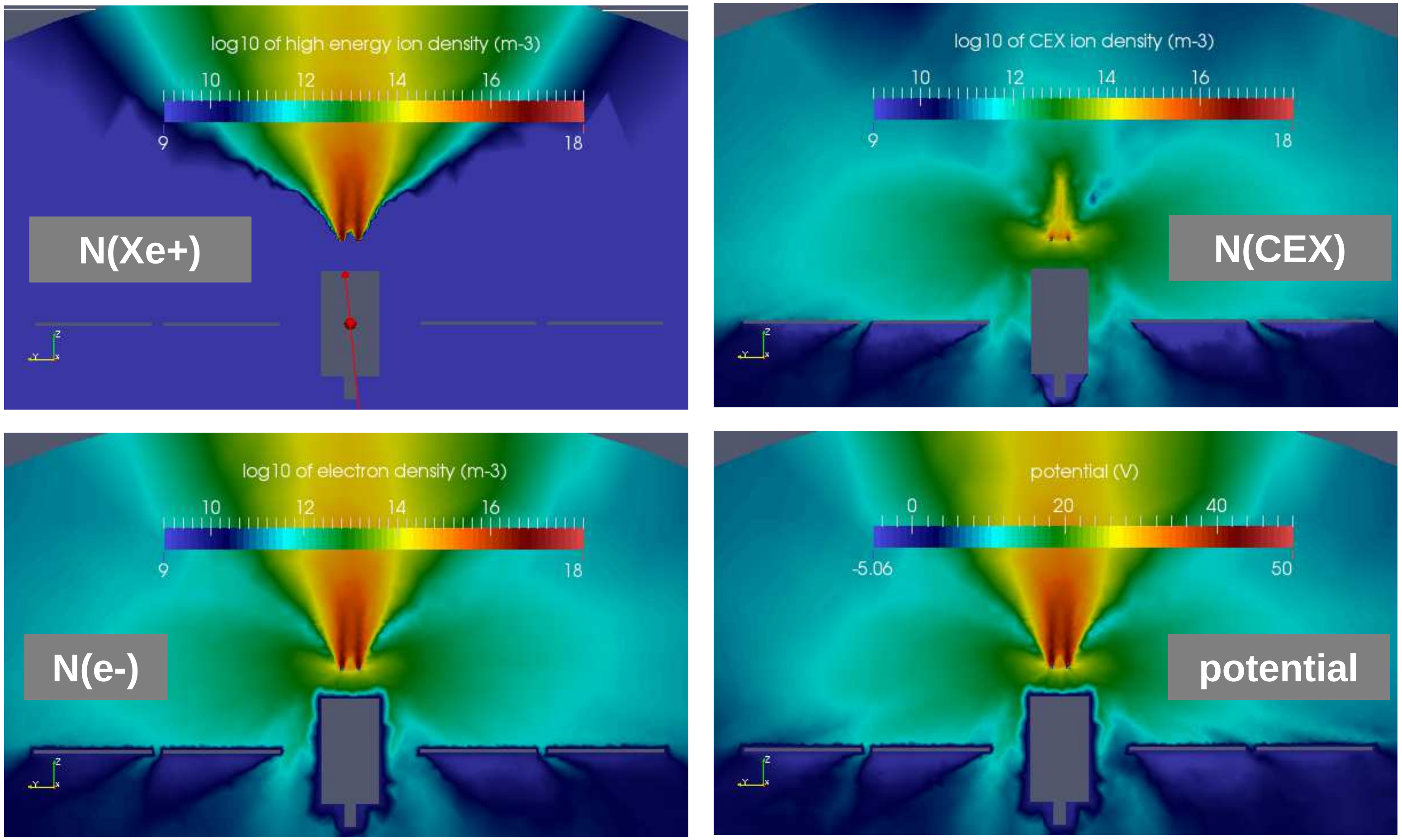
Multiple low-power thrusters (~SPT100 * 4)

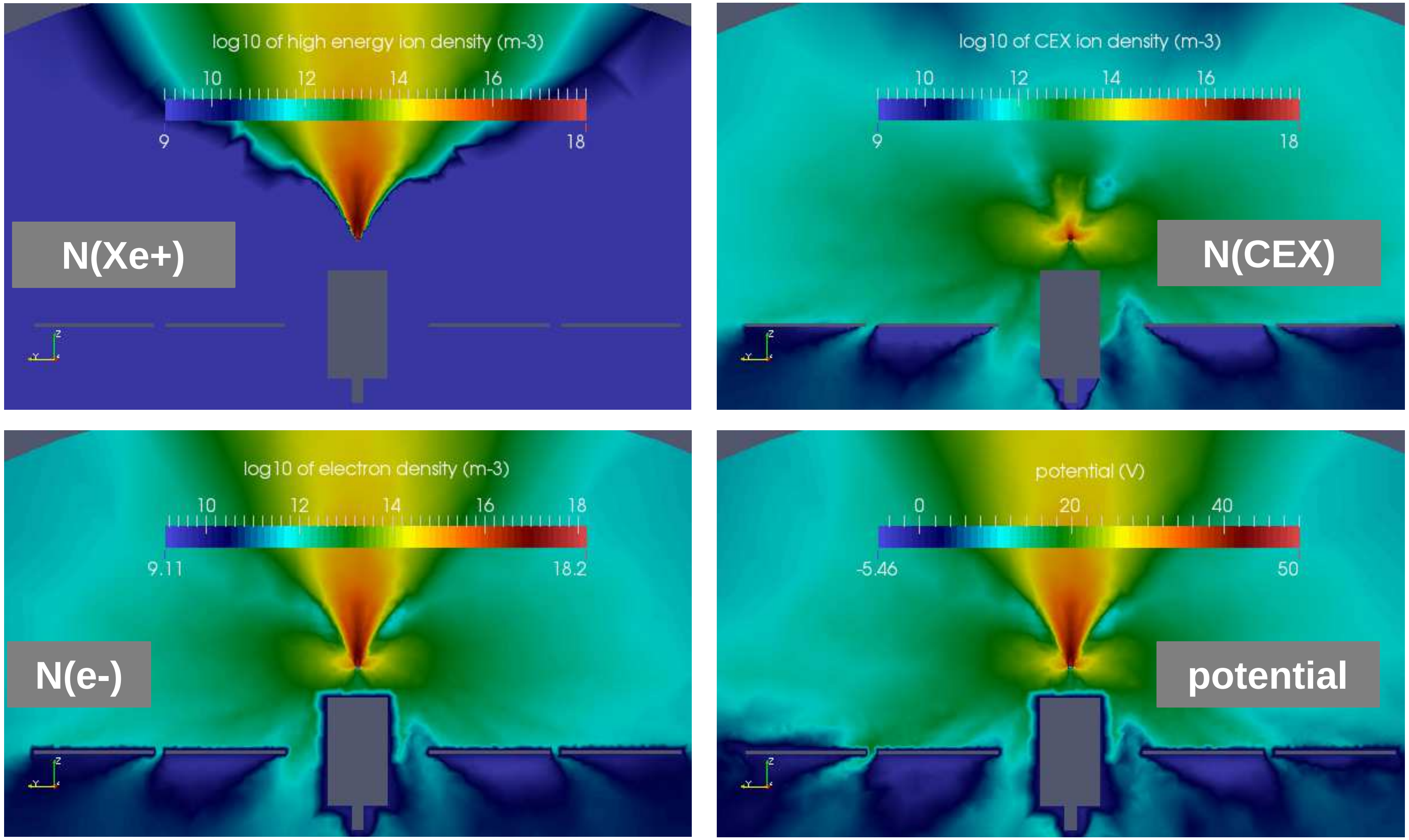
OPTION A



[CPU time ~3-5 hours
on 4 cores with 100 millions particles]

Single High-power thruster (~SPT 140 * 1)

OPTION B



Azimuthal profiles – Fast Xe+

High energy ions

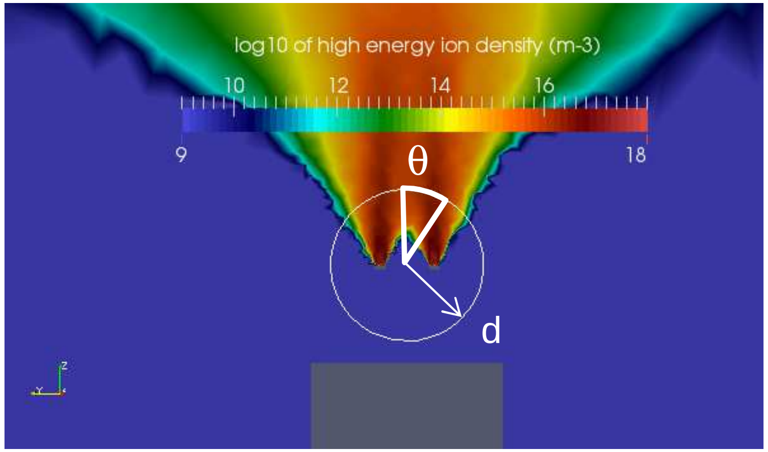
<u>Options A</u>

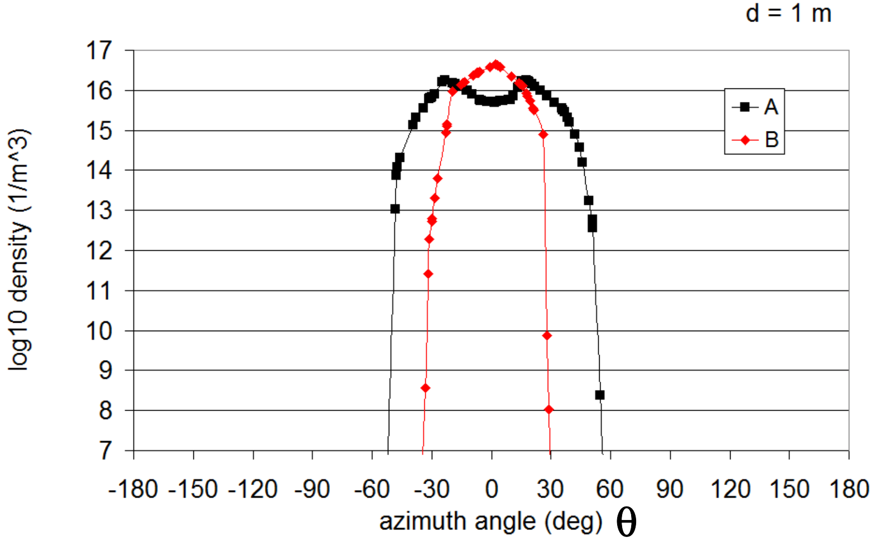
Maxima at ±30° (centerlines of thrusters)
Higher divergence of high energy ions
Smaller density in the global centerline

<u>Option B</u>

Larger density in the centerline
Qualitative agreement with EPIC*
Less divergent than 1f-PIC and 2f Hall2De*

**Lopez Ortega, 2015*





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Azimuthal profiles – CEX ions

(CEX) low energy ions

Option A

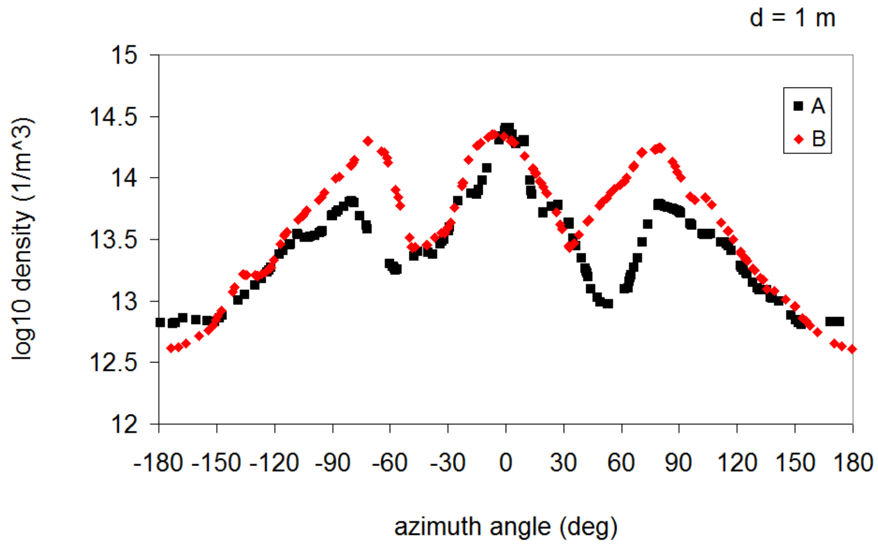
Maxima at 0° and ±80°

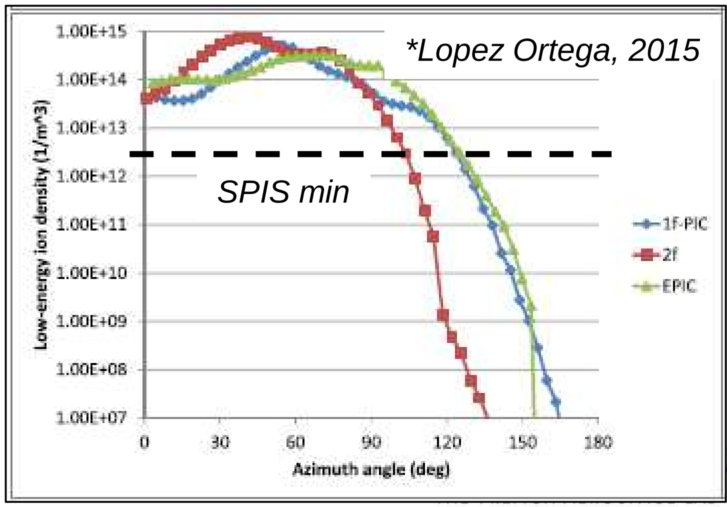
Option B

Maxima at 0° and ±70°
Higher divergence around 0°
Fluxes × 10 btw (-)45° and (-)120°
Fluxes ÷ 2 at 180°

Lopez Ortega*

Maxima at 0° and 45-70° pending on models
SPIS CEX divergence more pronounced
Expected by the MB electron law
Possibly combined with thruster case potential deflecting low energy ions





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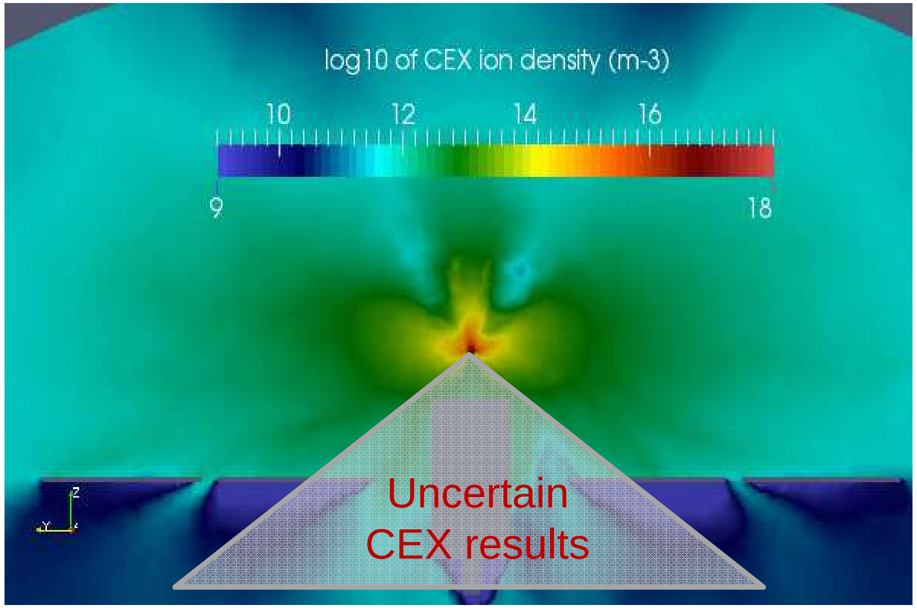

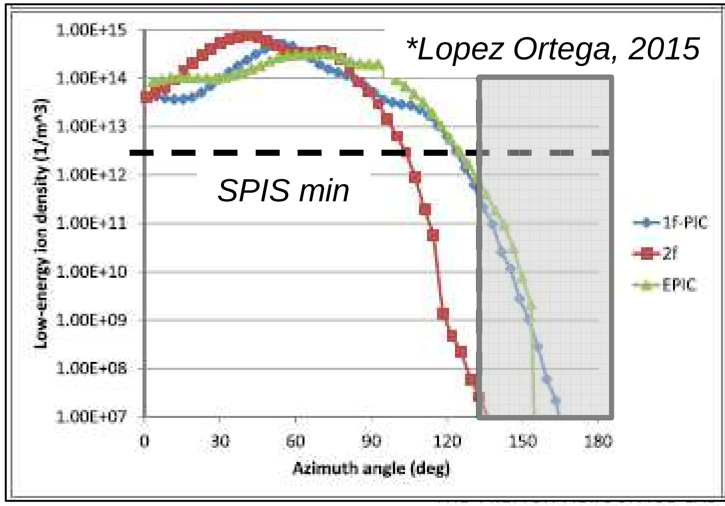

Plume and spacecraft charging during EOR

<u>Erosion during EOR</u>

Charging at GEO after EOR
Large antenna reflectors effects

Summary

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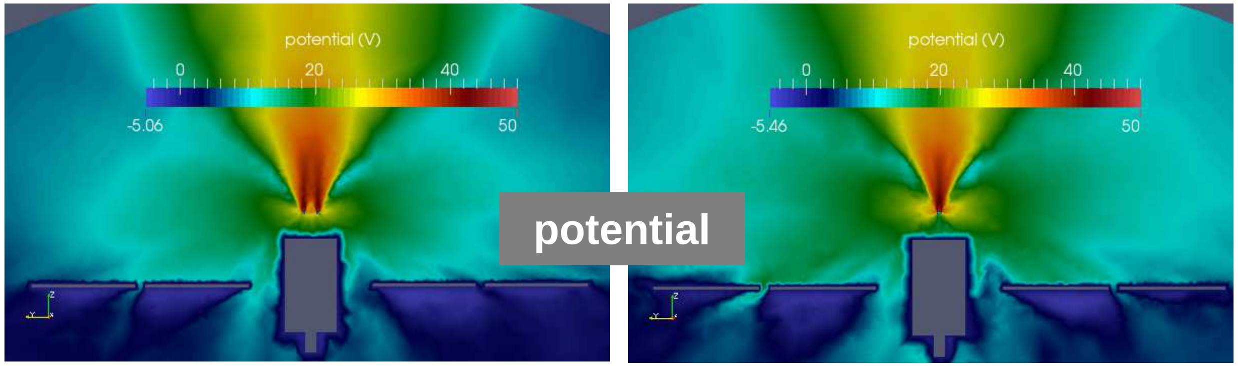
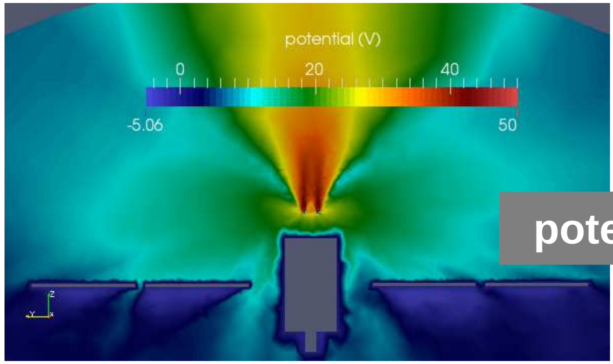
Option A Option B

SC Voltage
-2 V
Plume potential
+50 V
CEX energy
50 eV at impact

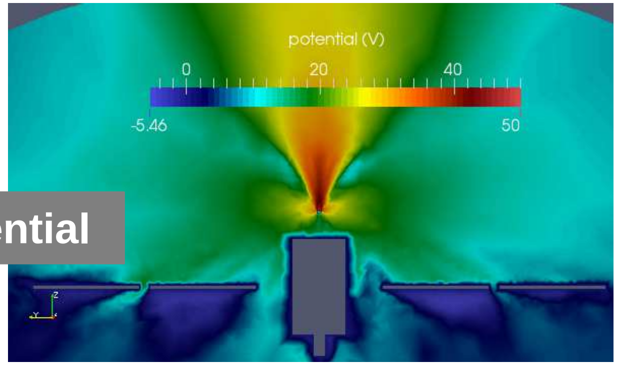
SC Voltage
-0.5 V
Plume potential
+50 V
CEX energy
50 eV at impact

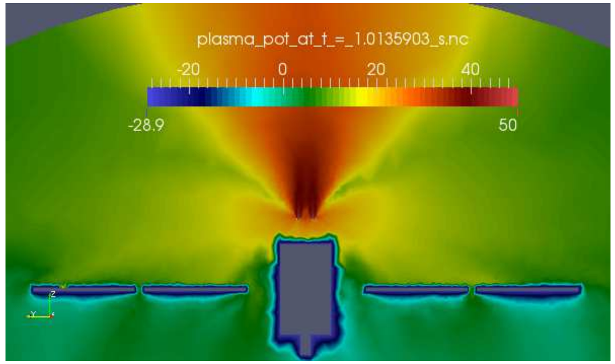


Option A	Option B	Option A & 50V_ic
SC Voltage -2 V **Plume potential** +50 V **CEX energy** 50 eV at impact	**SC Voltage** -0.5 V **Plume potential** +50 V **CEX energy** 50 eV at impact	**SC Voltage** -25 V **Plume potential** +50 V **CEX energy** 75 eV at impact



potential

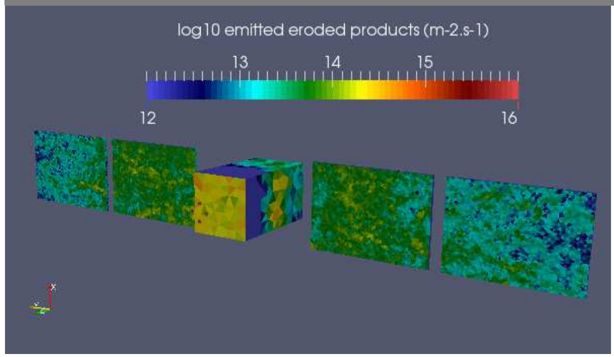




interconnects +50 volts

Option A	Option B	Option A & 50V_ic
SC Voltage	**SC Voltage**	**SC Voltage**
-2 V	-0.5 V	-25 V
Plume potential	**Plume potential**	**Plume potential**
+50 V	+50 V	+50 V
CEX energy	**CEX energy**	**CEX energy**
50 eV at impact	50 eV at impact	75 eV at impact

EROSION



CONTAMINATION

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Option A	Option B	Option A & 50V_ic
SC Voltage -2 V	**SC Voltage** -0.5 V	**SC Voltage** -25 V
Plume potential +50 V	**Plume potential** +50 V	**Plume potential** +50 V
CEX energy 50 eV at impact	**CEX energy** 50 eV at impact	**CEX energy** 75 eV at impact
Solar arrays erosion 10^{13} to 10^{14} $m^{-2}s^{-1}$ <u>1 nm in 7 days</u>	**Solar arrays erosion** 3.10^{13} to 3.10^{14} $m^{-2}s^{-1}$ <u>1 nm in 3 days</u>	**Solar arrays erosion** 4.10^{13} to 4.10^{14} $m^{-2}s^{-1}$ <u>1 nm in 2 days</u>
Solar arrays contamination 10^{11} to 6.10^{12} $m^{-2}s^{-1}$ <u>1 nm in 120 days</u> by thruster eroded products … possibly removed ultimately by CEX	**Solar arrays contamination** 3.10^{11} to 10^{13} $m^{-2}s^{-1}$ <u>1 nm in 70 days</u> by thruster eroded products … possibly removed ultimately by CEX	**Solar arrays contamination** 10^{12} to 10^{14} $m^{-2}s^{-1}$ <u>1 nm in 7 days</u> by thruster eroded products … Maybe not removed by CEX

Plume and spacecraft charging during EOR

Erosion during EOR

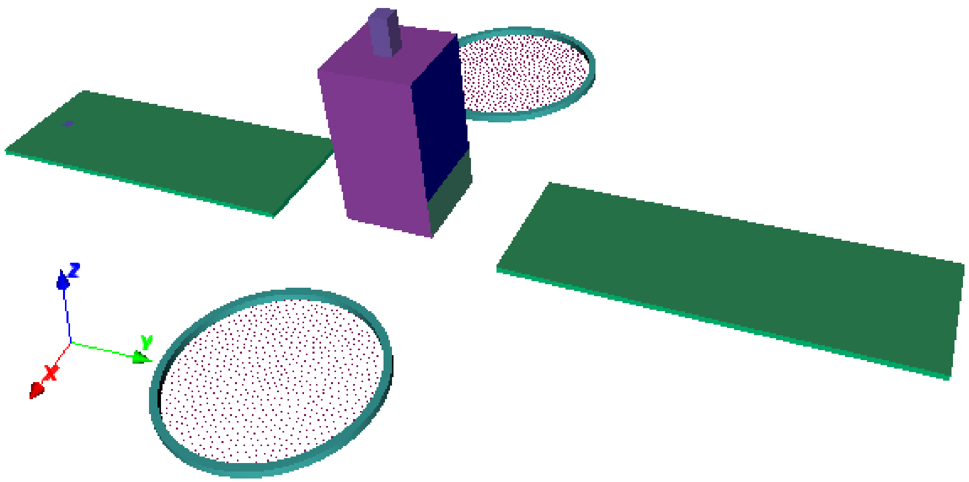
<u>Charging at GEO after EOR</u>
<u>Large antenna reflectors effects</u>

Summary

Charging at GEO after EOR

- Change of material surface due to erosion during EOR
  - ITO assumed totally removed from cover glasses
  - 25% of ITO removed from OSR
- Worst-case GEO environment for surface charging taken from ECSS

- Effect of large deployed mesh reflectors 5 m in diameters ?
  - Mesh : 30 OPI – 1mil → 94 % transparency
  - Study at different MLT



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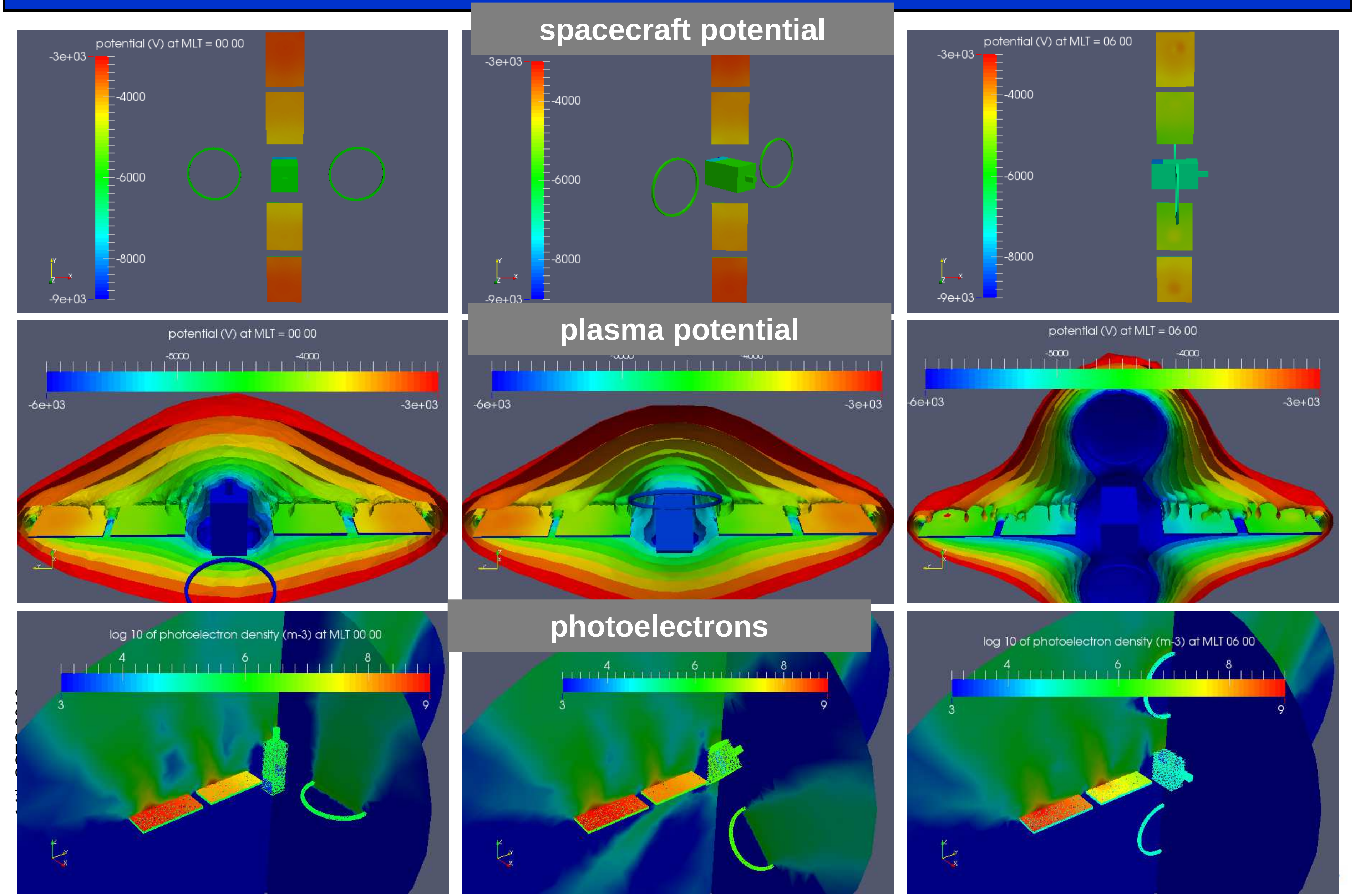
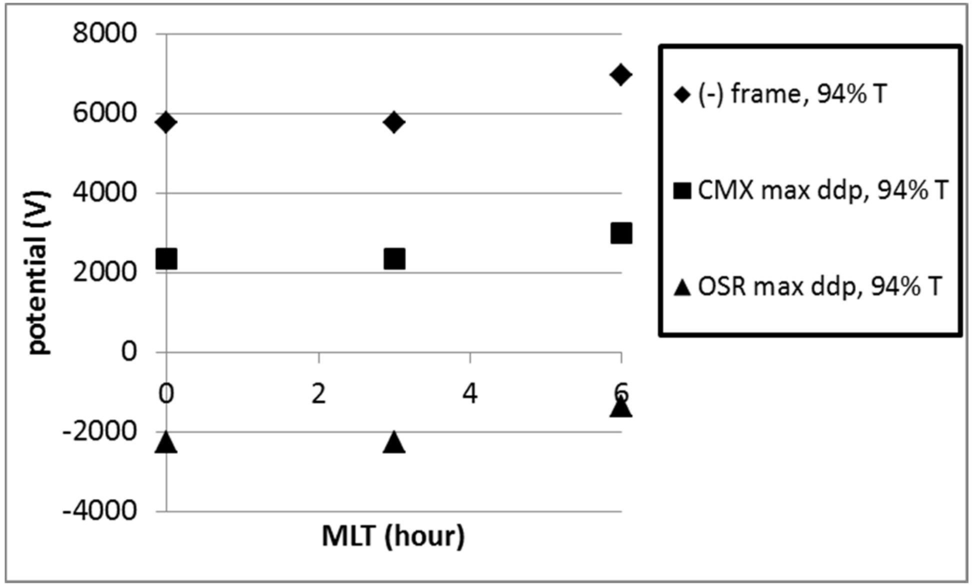
MLT 00 AM | MLT 03 AM | MLT 06 AM



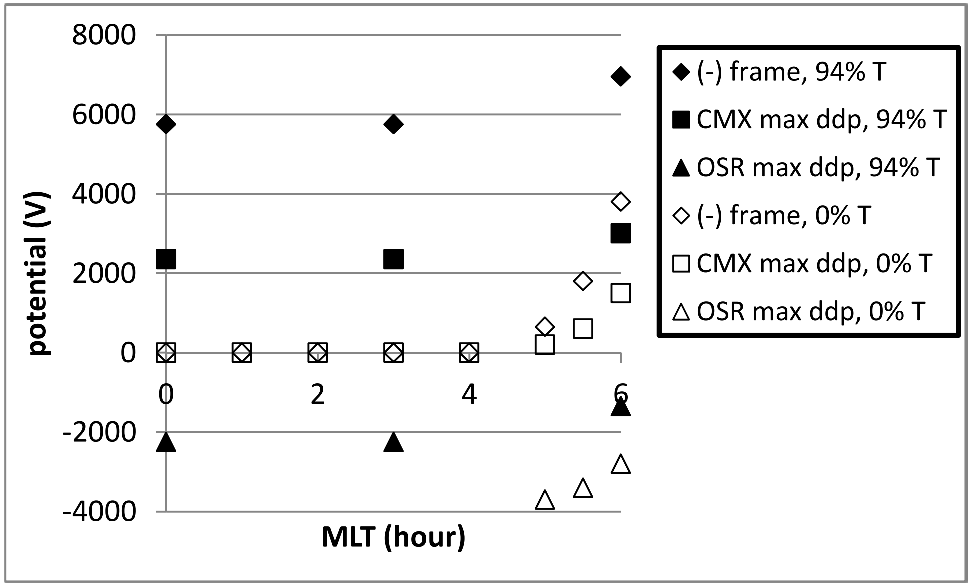
Charging state comparison

- Higher charging level at MLT ~6 because of reflectors orientation
  - Less photoemission
  - Larger barrier of potential for solar panels



Mesh vs Plain models

- Plain antenna (0% transparency) would charge less negative because of photoemission increase
- Necessity to model mesh transparency to be conservative



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<u>Summary</u>

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Summary

- Charging at GEO
  - Surface state significantly changed after EOR
  - Need to characterize erosion and contamination with dedicated experiments
  - Radiation effects also to be included (ageing, delayed radiation induced conductivity)
  - Confirmed role of sunlit conductive parts: mesh reflectors need appropriate modelling

- Plume modelling
  - 3D modelling necessary to account for plume/spacecraft dynamics
  - Erosion depends on spacecraft surface potential
  - <u>Rough estimations done as of today</u>

→ **Need for accurate spacecraft potential**

- Role of neutralization electron ?
- Solar array collection current ?
- Cathode electrical circuit : floating ? grounded ?
- Spacecraft attitude: rotating solar arrays ? orientation of thrusters ?

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Next steps

- ESA TRP activities started 2015-2016
  1. Electron Cooling model (ESA TO K. Dannemayer)
     - Airbus DS (C. Théroude), ONERA, UC3M, ICARE, KTH
     - Advanced hybrid models & plume measurements
     - See poster 03 by F. Cichocki
  2. SPIS-EP (ESA TO A. Hilgers)
     - ONERA (S. Hess, P. Sarrailh), ARTENUM, AIRBUS DS, TAS
     - UR gathered from ESA and from the 22nd SPINE community (March 23-24, 2016)
     - Aspects covered: cathode current, multiple thrusters, distributions of ions, plasma interaction with the power units, interconnects, chemistry, erosion, contamination, dedicated outputs, …
  3. High Power High Voltage (ESA TO G. D’accolti)
     - Airbus (A. Gerhard), ONERA
     - Plasma current collection on high voltage solar arrays
     - See ppt by S. Hess April 7, 2016 PM + poster 52 by JM Siguier
- ONERA/CNES PhD
  - Multi scale simulation of electric propulsion, spacecraft and interconnects
  - See next ppt by A. Brunet

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References

- Hu and Wang, Electron properties in collisionless mesothermal plasma expansion: fully kinetic simulations, IEEE Trans. Plasma Phys., Vol 43, 9, 2015.
- Lopez Ortega et al., Self consistent model of high-power Hall thruster plume, IEEE Trans. Plasma Phys., Vol 43, 9, 2015.

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Acknowledgments

- Didier Lazaro, Denis Packan and Nicolas Bérend from ONERA for discussions on EOR orbits
- Justin Likar from UTC Aerospace Systems for spacecraft definition

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