Modelling satellite interaction with space environment and weather

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Outline

Spacecraft environment interaction

- Current collection from ambient plasma
- Solar radiation
- Radiation belts and energetic particles in the auroral region and polar cap.
- Precipitation of energetic particles in the auroral and polar regions.
- Micrometeorites
- Space debris
- Other spacecraft

Impact on satellites and instruments

- Charging (Surface and internal)
- ESD events
- Sheath formation
- Potential barriers
- Material ageing

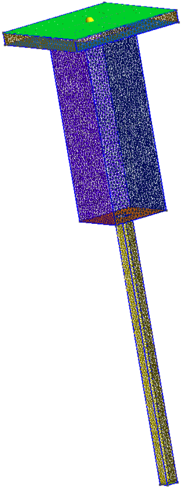
Modelling

- Goal: Predict spacecraft-environment interaction
  - under realistic conditions,
  - with a high level of confidence.
- Some of the models in use include:
  - EMSES
  - iPic3D
  - MUSCAT
  - Naskap-2k
  - PTetra
  - SPENVIS
  - SPIS
  - ...

PTetra

- Fortran 90, no GUI or ancillary tasks.
- Fully kinetic Particle In Cell (PIC).
- Adaptive unstructured tetrahedral mesh.
- Explicit, electrostatic, but accounts for uniform background $\vec{B}_0$ and computes 1^{st} order $\vec{B}_1$.
- Imposition of electrical bias and collected current on selected components.
- Arbitrary number of electron and ion species with user defined: Density, drift velocity and temperature.
  For ions: charge and mass.
- Charging from charged particle collection.
- Photoemission.
- Secondary electron emission from electron impact.

Solar Probe Geometry



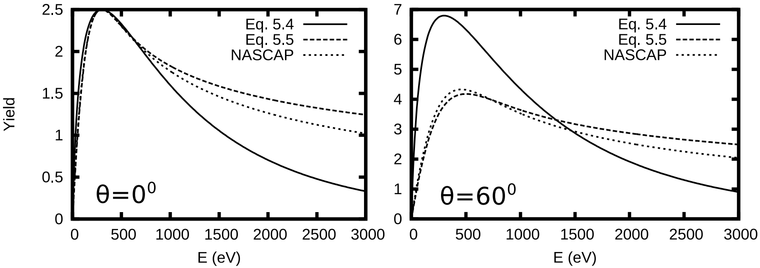
(See poster by Deca, et al.)

Physics parameterization

- Many physical processes cannot be modelled from first principles.
  $\rightarrow$ Need for empirical parameterization.
- Ex.: Photoemission and secondary electron emission from electron or ion impact.
- Incident particle reflection from surfaces.
  - Dependence on energy and angle of incidence.
  - Distribution of emitted/reflected particle in energy and angle.
- Surface properties and ageing.
  - Contamination, and capacitive layers.
  - Conductivity.
  - Rugosity.

Example: Secondary electron emission

- Different empirical yields are found in the literature.



Eqs. 5.4 and 5.5 are from Hastings and Garrett (2004).
NASCAP: Thanks to J.-C. Matéo Vélez.

Journey

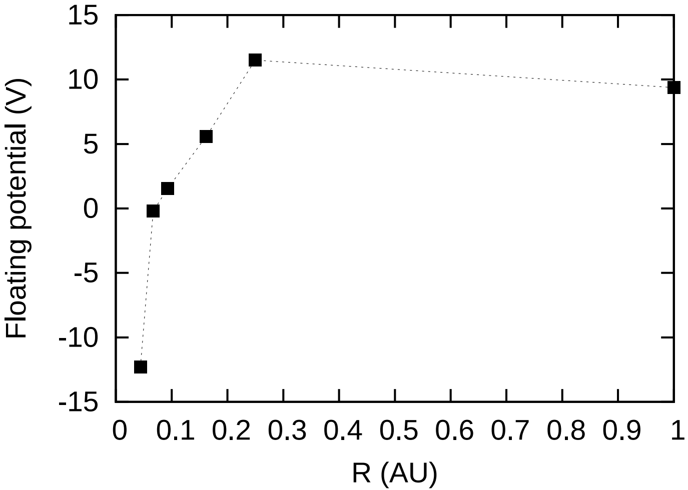
- Under "normal" conditions:

$R(AU)$	$n_e(10^6 m^{-3})$	T_e(eV)	T_i(eV)	$v_{sw}(km/s)$	$B(nT)$
0.044	7000.	84.47	87.25	300.0	2100.
0.067	1940.	59.25	67.00	335.0	1380.
0.093	1140.	48.33	55.82	350.0	476.
0.162	310.	31.77	39.70	366.0	157
0.250	119.	22.95	30.76	401.4	67.
1.000	6.93	8.14	8.00	430.0	5.8

(Guillemant, et al., IEEE Trans. Plasma Physics, in press.)

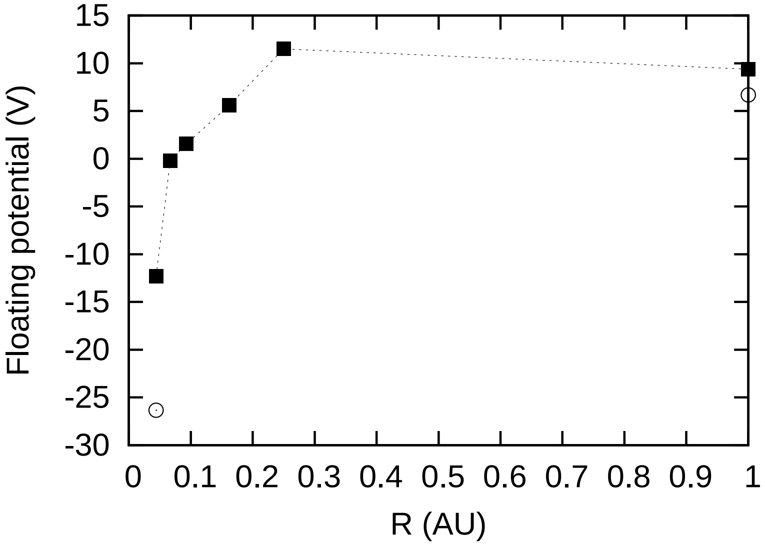
- Under "extreme" conditions (flares, CMEs, impacts near Lagrange points)?

Floating potential at different positions



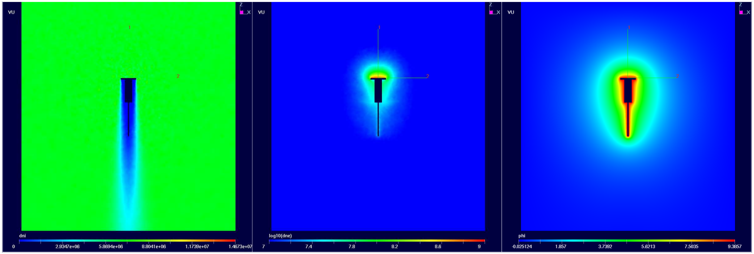
Effect of a CME

Density and Solar wind speed increase by ~ 2.

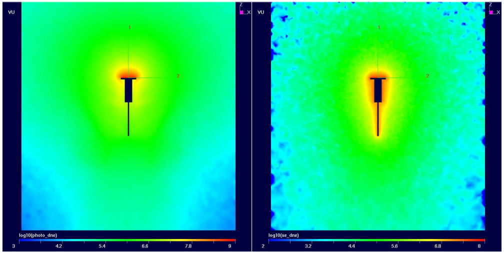


$R = 1AU, \; V = 9.38V$

n_i $\qquad$ $log(n_e)$ $\qquad$ ϕ

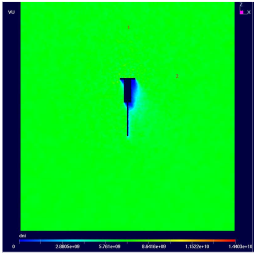


$log(n_{e-ph})$ $\qquad$ $log(n_{e-se})$

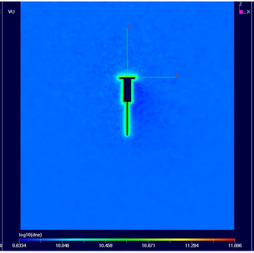


$R = 0.044AU,\ V = -12.3V$

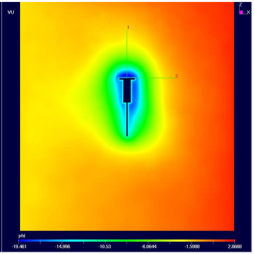
n_i



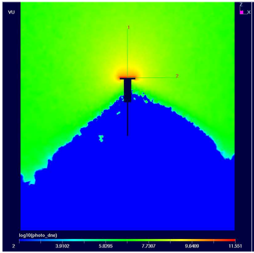
$log(n_e)$



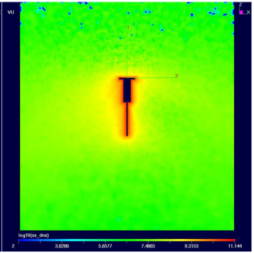
ϕ



$log(n_{e-ph})$



$log(n_{e-se})$



Some findings

- The potential varies monotonically away from the spacecraft when $V > 0$.
- Close to the sun, despite the high photoelectron and secondary electron yields, the $V < 0$ due to a potential barrier.
- An electron barrier forms when
  - there is a 'cold' dense electron cloud near the SC surface, localised in a layer of thickness $d < \lambda_{thermal}$.
  - The distance between this layer and the surface is smaller than the linear scale of the spacecraft.

See poster by J. Deca, et al. for a detailed analysis of these effects.

Summary 1

- Between perihelion and aphelion, SPP will go through different regimes interaction with its environment:
  - "Linear" near aphelion: $V > 0$ because relatively low contribution to charging from ambient plasma and important photoemission.
  - "Saturated emission": $V < 0$.
    Because of the formation of a 'cold' electron potential barrier, a change in photoemission or secondary electron emission yield produces a relatively much smaller change in the net rate of emission A large faction of emitted electrons are reflected by the barrier and recollected by the spacecraft.
- In the saturated emission regime, the SC potential and the sheath (barrier) surrounding it are relatively insensitive to photoelectron and secondary electron yields.

Summary 2

- These yields, however, make a difference in the linear regime when the various contributions to emission are approximately additive.
- Different empirical parameterizations exist for the same phenomena.
- Moreover, material ageing will cause material properties and yields to vary in time.
- The main difficulty in making accurate prediction comes from the uncertainty in the empirical parameterization of physical processes.