Dust models in SPIS

S. Hess, and the members of the consortia involved in the Dusty Environment and SPIS-DUST projects

ESA contracts

European Space Agency
Agence spatiale européenne

ONERA
THE FRENCH AEROSPACE LAB

ARTENUM, PARIS
Science & Groupware

LANCASTER
UNIVERSITY

SPIS-Dust

Version of SPIS developed by ONERA and ARTENUM under ESA contracts.

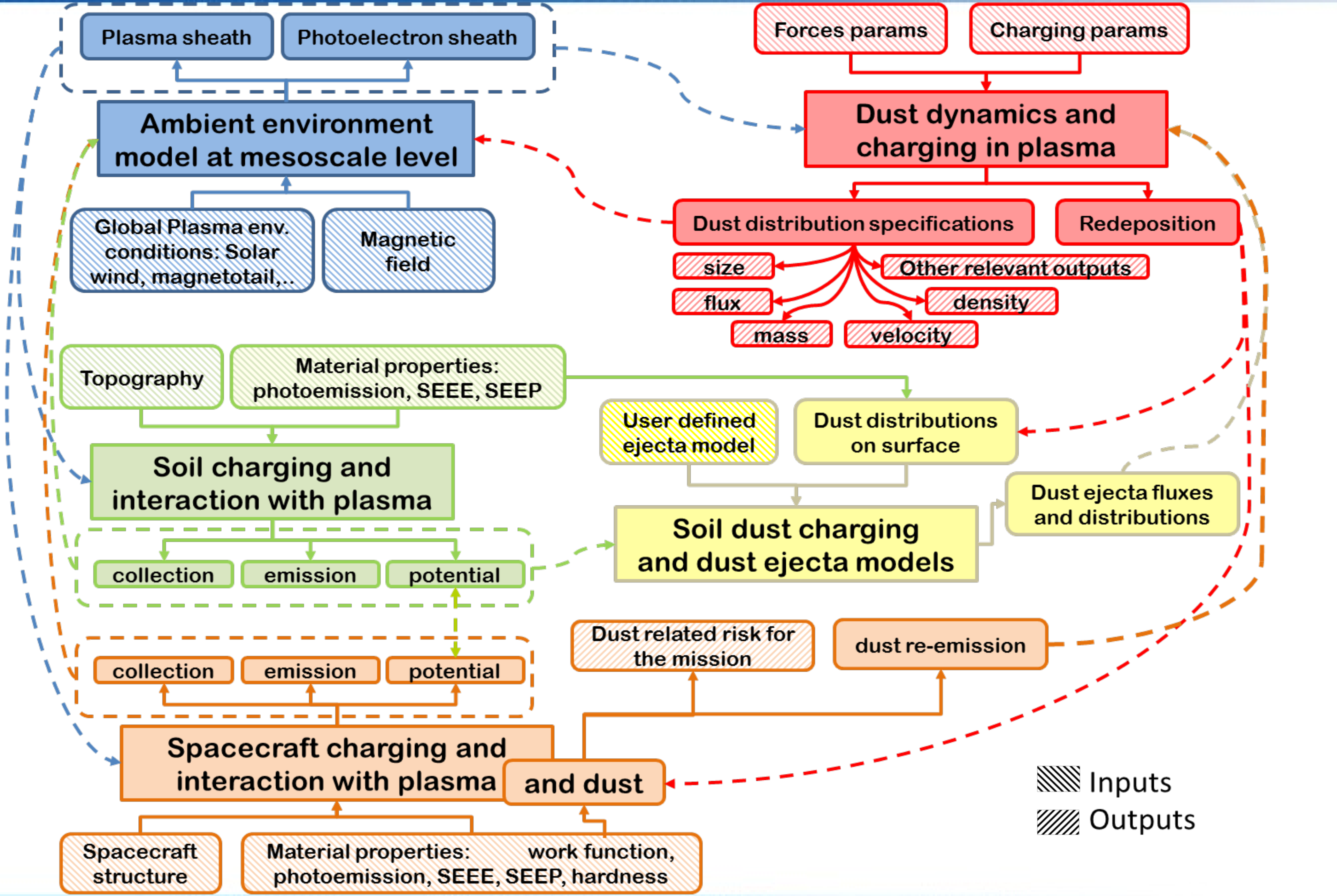
It introduces the physics of dusts in space plasma, and their interaction with spacecraft.

particles with dust characteristics (radius, ...)
new forces in the plasma: photon pressure, gravity and on surface: vibration, cohesion,...
dust-plasma interaction: charge collection and emission, charge evolution
physical model of the dust charging on surface and subsequent dust grain emission
new models: 1D plasma sheath boundary conditions, dipole magnetic field,...
new diagnostics instruments: distributions, trajectory sensors, risk matrix,...

It also benefits from new UI capabilities:

geometry generation from DTM
merging of objects/spacecraft
global and local parameters can be lists/matrices
live monitoring of complex instruments

SPIS-DUST Architecture



Plasma sheath

Photoelectron sheath

Ambient environment model at mesoscale level

Global Plasma env. conditions: Solar wind, magnetotail,..

Magnetic field

Forces params

Charging params

Dust dynamics and charging in plasma

Dust distribution specifications

Redeposition

size

flux

mass

velocity

density

Other relevant outputs

Topography

Material properties: photoemission, SEEE, SEEP

Soil charging and interaction with plasma

collection

emission

potential

User defined ejecta model

Dust distributions on surface

Soil dust charging and dust ejecta models

Dust ejecta fluxes and distributions

collection

emission

potential

Dust related risk for the mission

dust re-emission

Spacecraft charging and interaction with plasma and dust

Spacecraft structure

Material properties: work function, photoemission, SEEE, SEEP, hardness

▧ Inputs

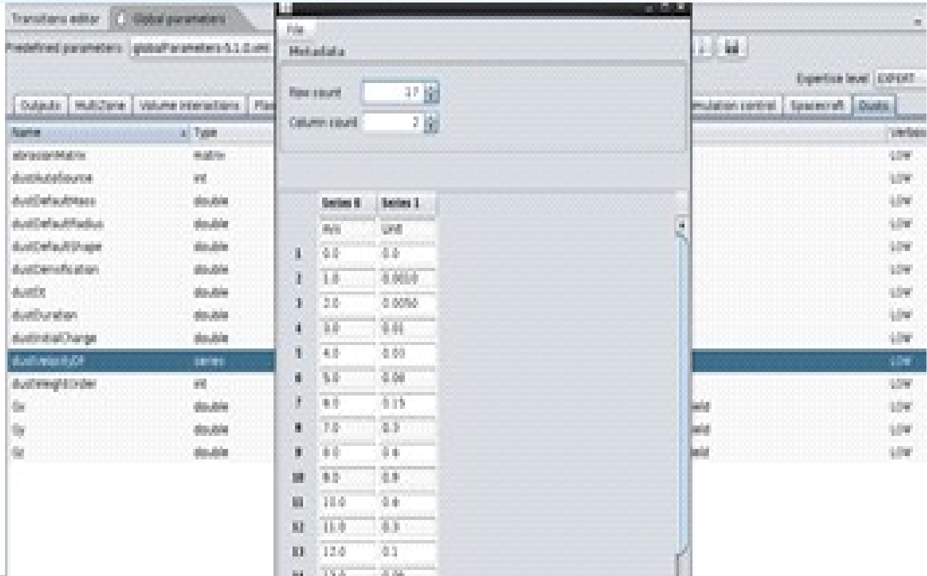
▨ Outputs

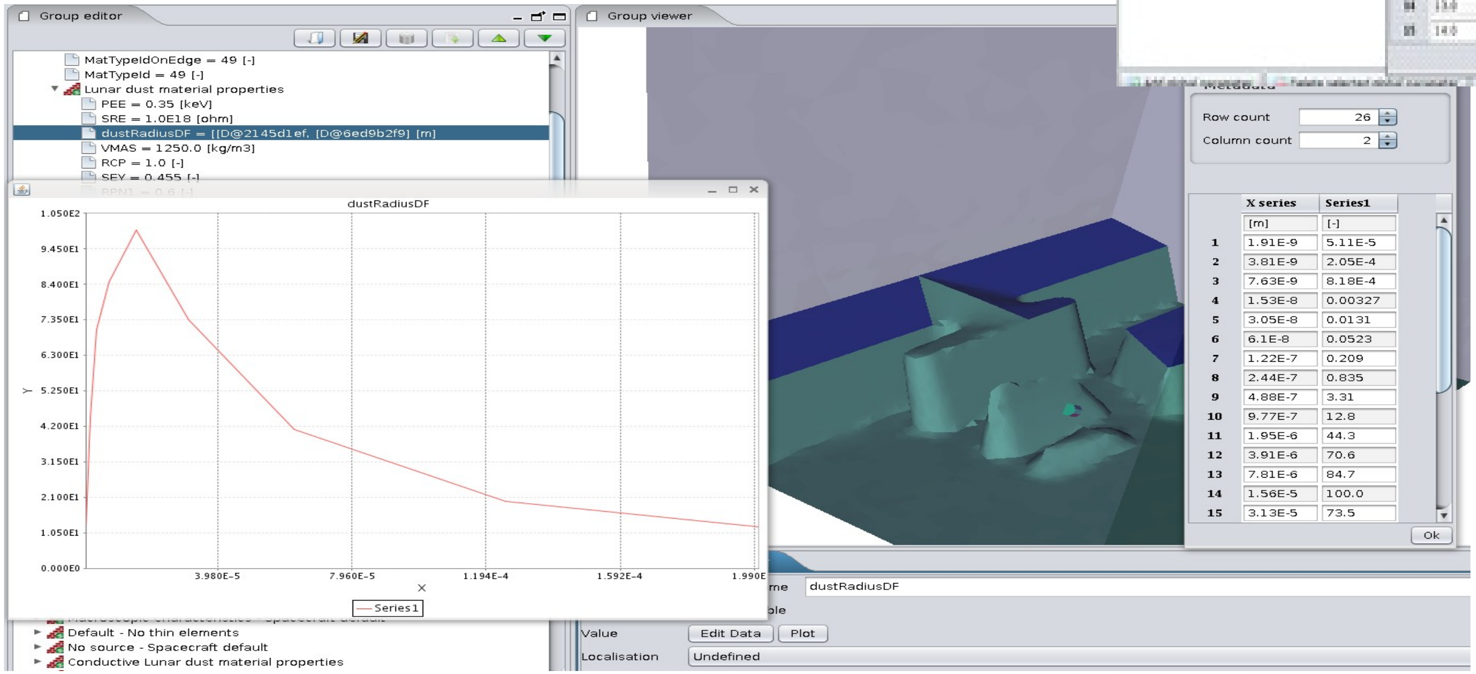
Dust particles

Dusts are a totally new kind of particles in SPIS.
Dusts are characterized by:

- a radius
- a mass depending on the radius
- a charge that may vary

All these characteristics are different for each particle. They are defined as distributions.





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MatTypeId = 49 [-]
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PEE = 0.35 [keV]
SRE = 1.0E18 [ohm]
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VMAS = 1250.0 [kg/m3]
RCP = 1.0 [-]
SEY = 0.455 [-]
RPN1 = 0.6 [-]
Default - No thin elements
No source - Spacecraft default
Conductive Lunar dust material properties

Row count 26
Column count 2

	X series	Series1
	[m]	[-]
1	1.91E-9	5.11E-5
2	3.81E-9	2.05E-4
3	7.63E-9	8.18E-4
4	1.53E-8	0.00327
5	3.05E-8	0.0131
6	6.1E-8	0.0523
7	1.22E-7	0.209
8	2.44E-7	0.835
9	4.88E-7	3.31
10	9.77E-7	12.8
11	1.95E-6	44.3
12	3.91E-6	70.6
13	7.81E-6	84.7
14	1.56E-5	100.0
15	3.13E-5	73.5

Name dustRadiusDF
Value
Localisation Undefined

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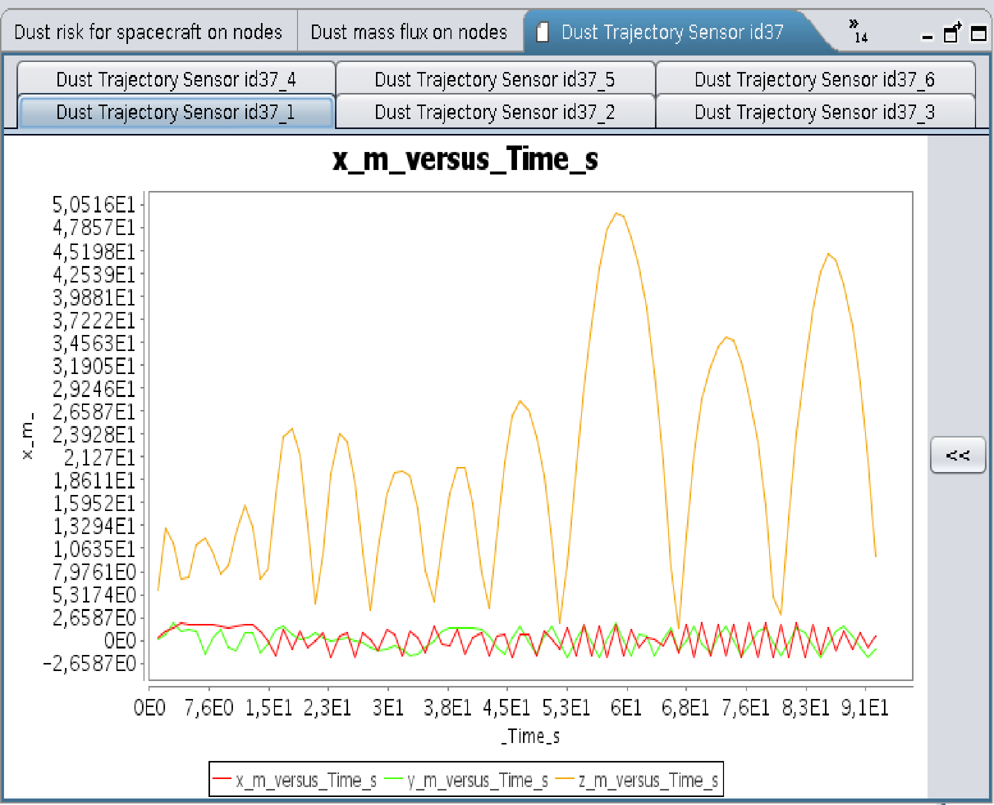
Dust feels extra forces:

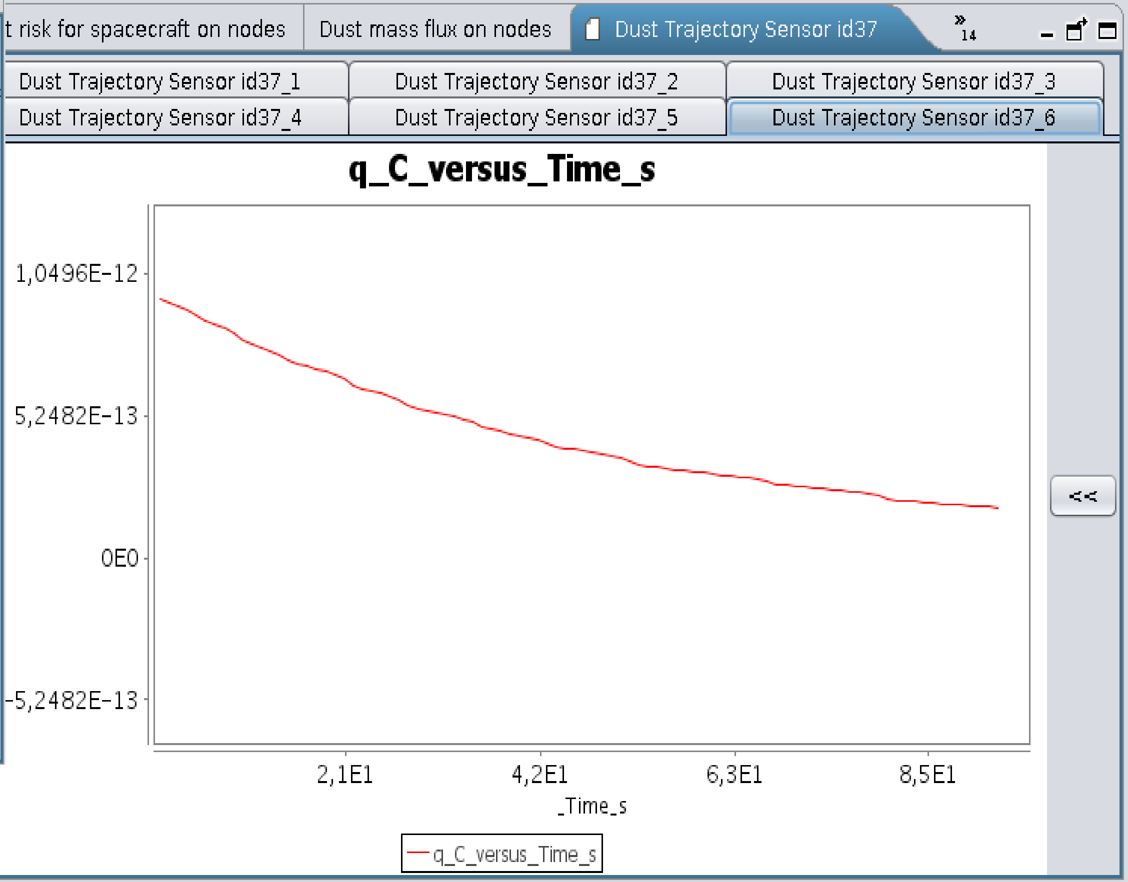
- gravity (also applied to other particles)
- photon pressure

Dusts have some particular interaction:

- charge collection (computed through OML or MCC)
- SEEE, model of Chow et al., 1999 is implemented
- photo-emission

These interactions lead to the evolution of their charge.





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Dust charging on the ground

The dusty soil is a complex surface to charge, composite of rocks and dusts

- the surface charges as a spacecraft surface, for which we defined a lunar surface material with the usual properties.
- the dust particles charge differentially. The total amount of charges to share between dusts is obtained from the Gauss theorem ($Q=\varepsilon_0 \sigma E$).

In SPIS, only the surface charge variation are shared between dust macroparticles.

There are no models of the charging of dust charging of the ground. Two ways of sharing charge between dusts of different size:

- proportional to their cross-section ($\propto r^2$)
- proportional to their capacitance ($\propto r$), *default in SPIS*

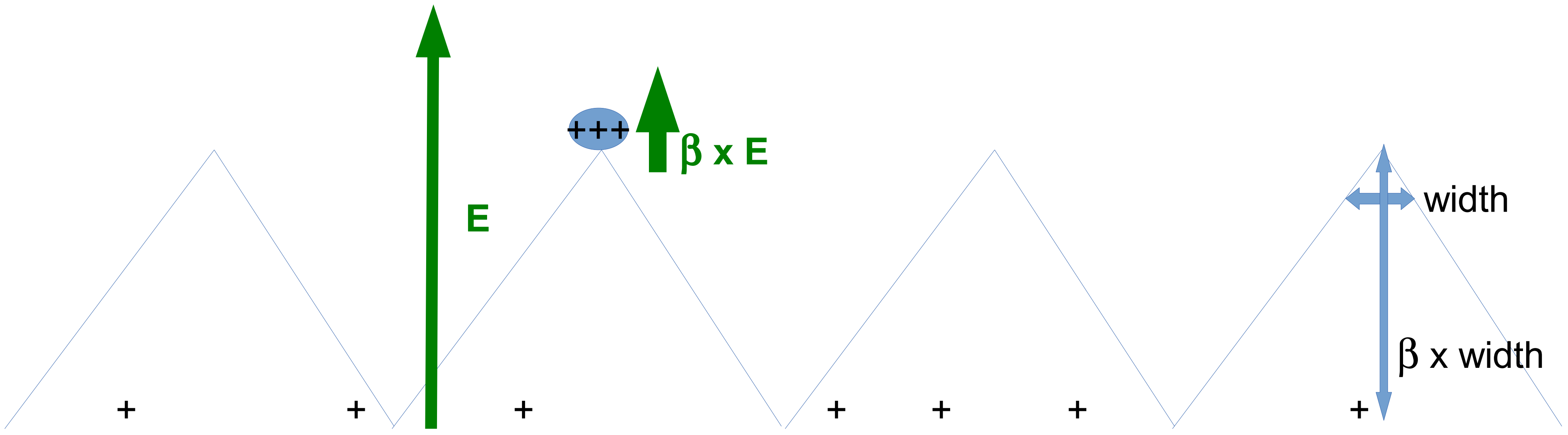
Problem: Averaged charge for a micron-sized dust grain on the lunar surface at the equator at noon (surface normal electric field ~ 2V/m) is 0.0001 ecu!
Charge must be differentially shared between dusts with the same characteristics.

Dust charging on the ground

We built a model based on the tip model:

Ground irregularities as modelled as tips with a width/height and width/distance ratios β. Tips corresponding to a ratio β cover a fraction of the surface β^{-2}.

Tip effect: charges migrate to the end of the tip (i.e. to the dust on the top of the ground irregularity). The charge density in the material and the local electric field are both enhanced by a factor β. The electrostatic force on the dust multiplied by β^2



Dust charging on the ground

Dusts are emitted if the force balance is favourable:

$$q\beta^2 E - KS^2 r - mg + F_S > 0$$

Cohesive force

In this case a macro-particle with a weight divided by β is emitted with a charge given by the capacitive coupling with the ground and triboelectric effect:

$$Q=4\pi\varepsilon_0 rV + (Q_r.r+Q_w)(W-W_{dust})$$

The dust velocity corresponds to the dust acceleration over a distance equal to its radius. The distribution of the β factor is transposed into a probability on the ejection velocity, then the velocity is randomly obtained following this law.

The number of dust emitted per time step depends on the charging time of single dust in the dust layer, which itself depends of the conductivity of the dust layer r. The weight is multiplied by $\sigma\Delta t/\varepsilon_0$.

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Model parameters

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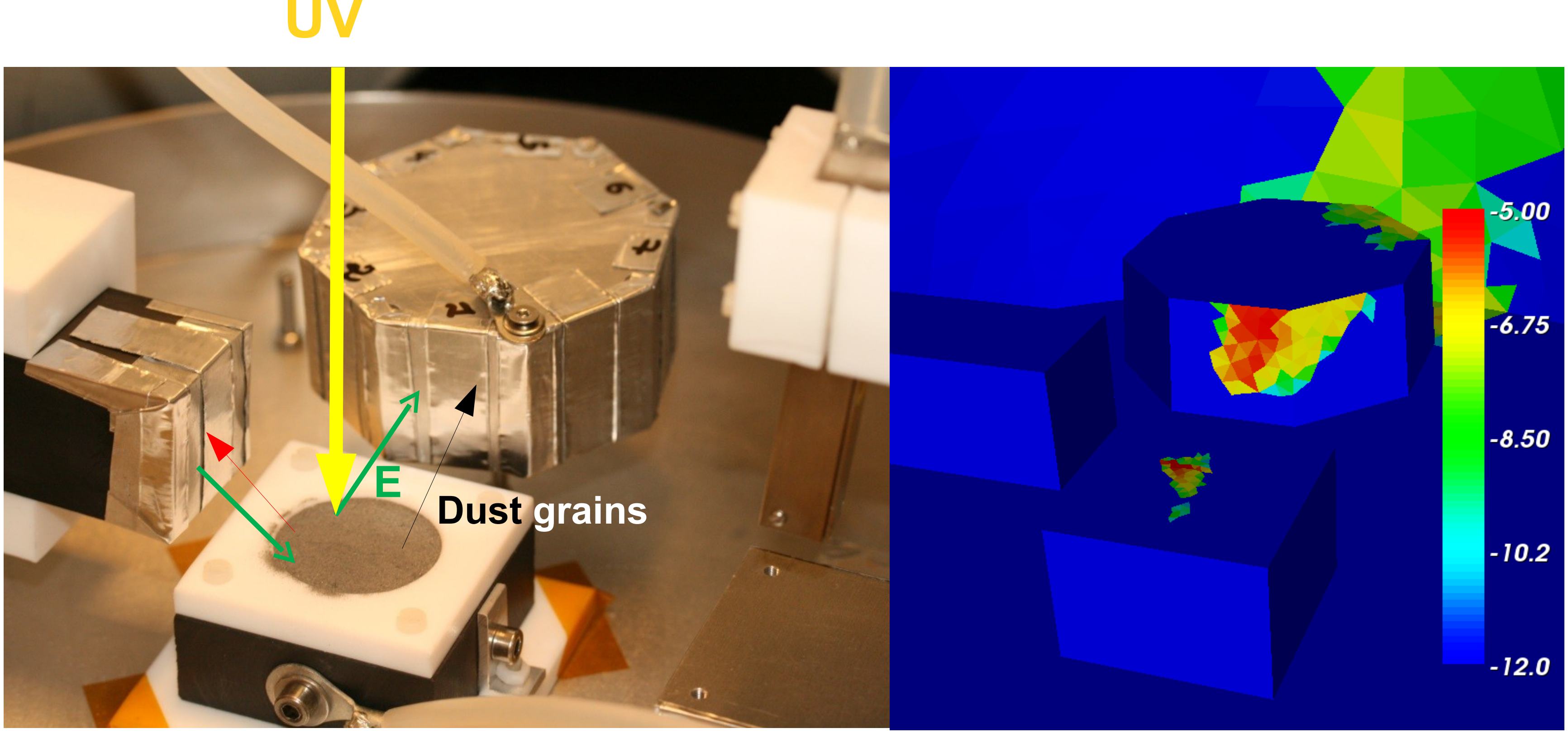
Model experimental validation

For a polarization of 3000 V SPIS seems to overestimate the amount of dust deposited by a bit more than one order of magnitude...and that is a relatively good match:

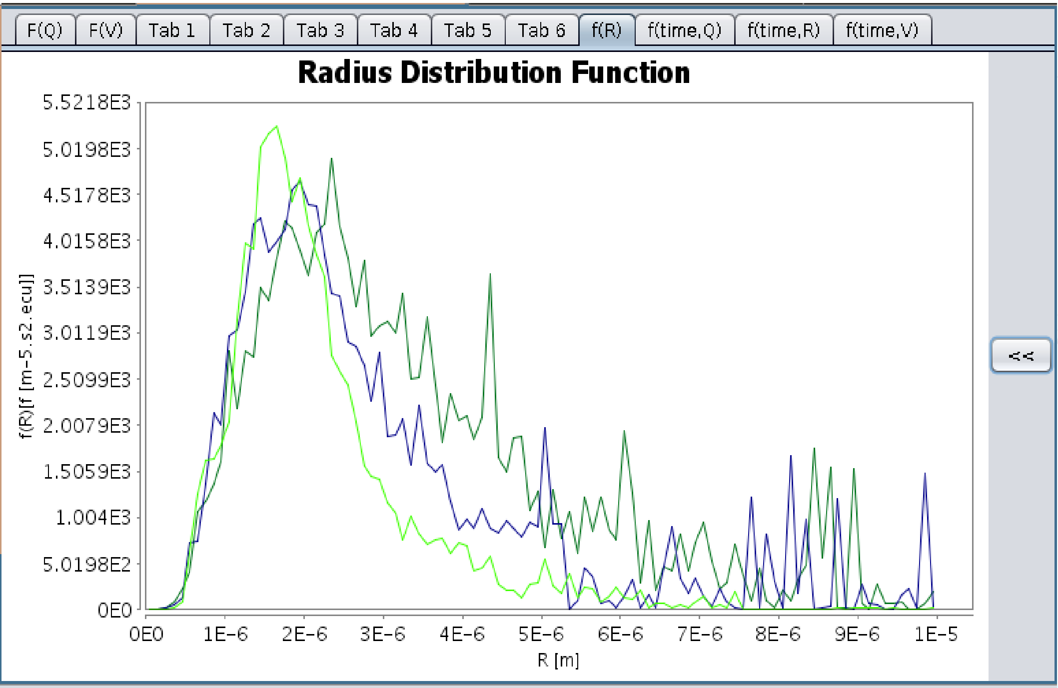
Model parameters are “known” with an error of four orders of magnitude

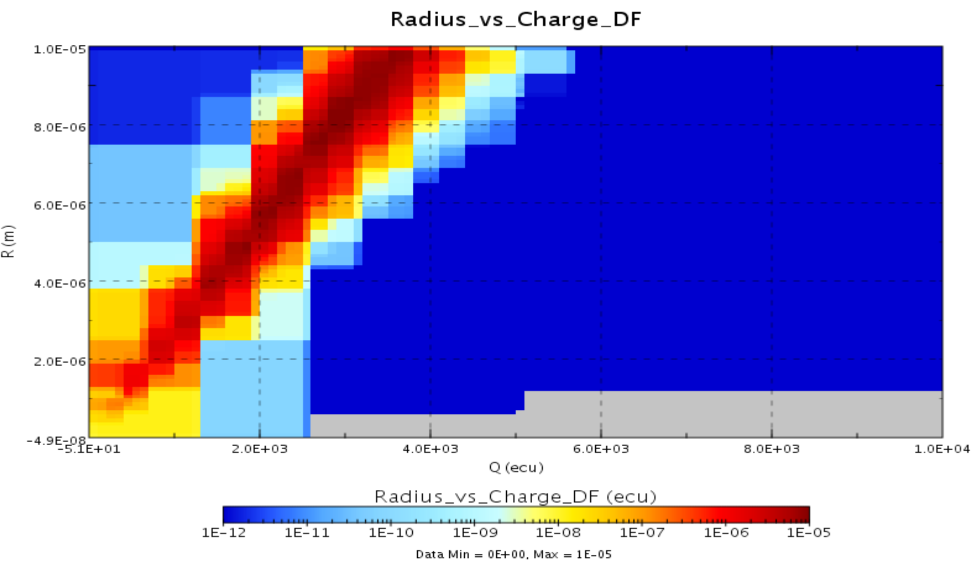


Dust particle detector

Backtracks dusts from the detector to boundaries or surfaces including the dust interaction with the plasma.

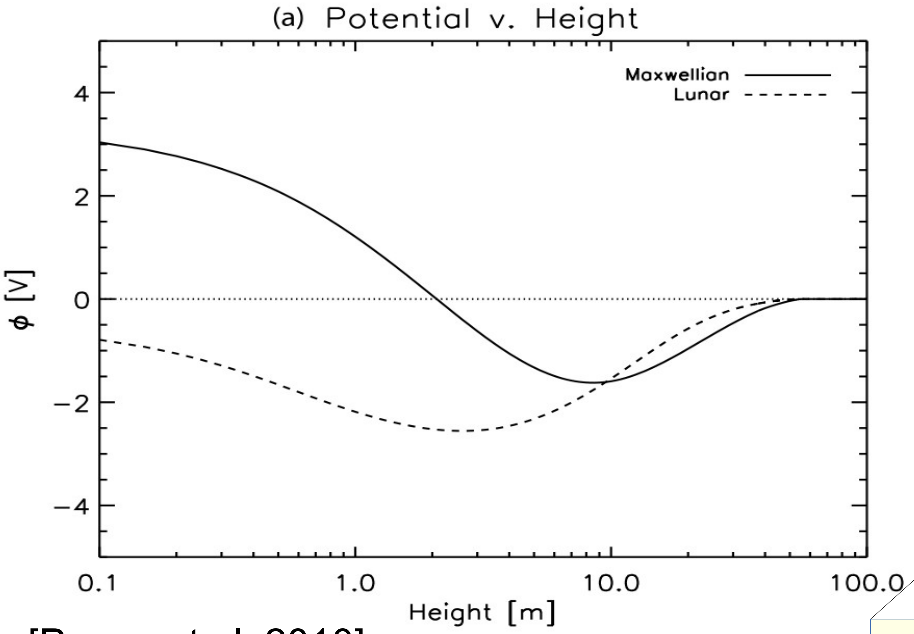
The charge, velocity and radius distribution on the detector is obtained from that on the surfaces (either user specified or using the SPIS charging and ejection model)





Plasma Sheath and boundary conditions

Simulate the sheath above a surface in a simulation box with a single opened face.



[Poppe et al. 2010]

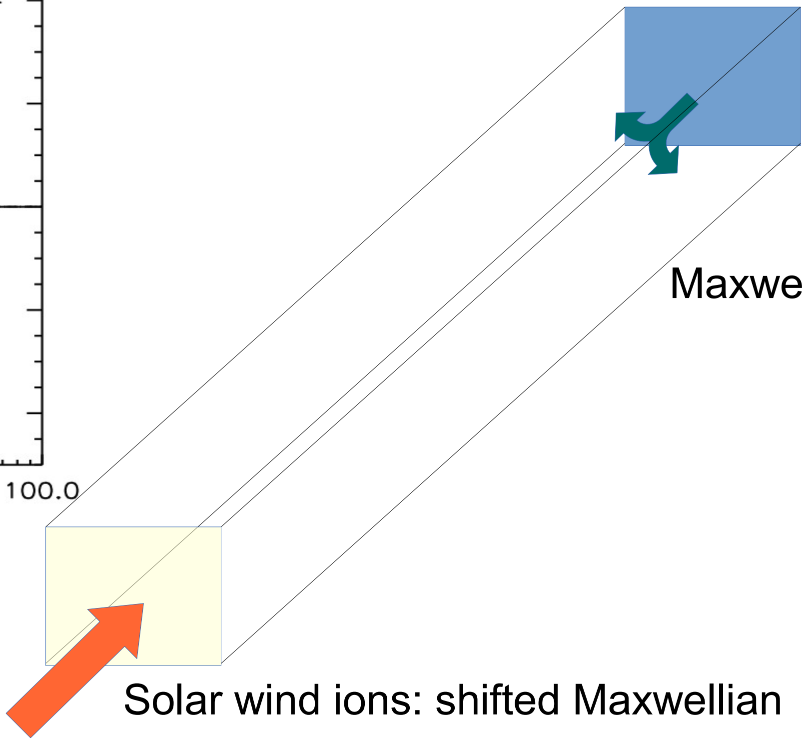


Photo-electrons:

Maxwellian J_ϕ=4.5 10^{-6} A.m^{-2}

v_ϕ = 0 km/s

T_ϕ = 2.2 eV

Solar wind ions: shifted Maxwellian n_{io} ~1-1.5 10^7 m^{-3}

v_{io} =400 km/s

T_{io} =10 eV ($v_{ti} << v_0$)

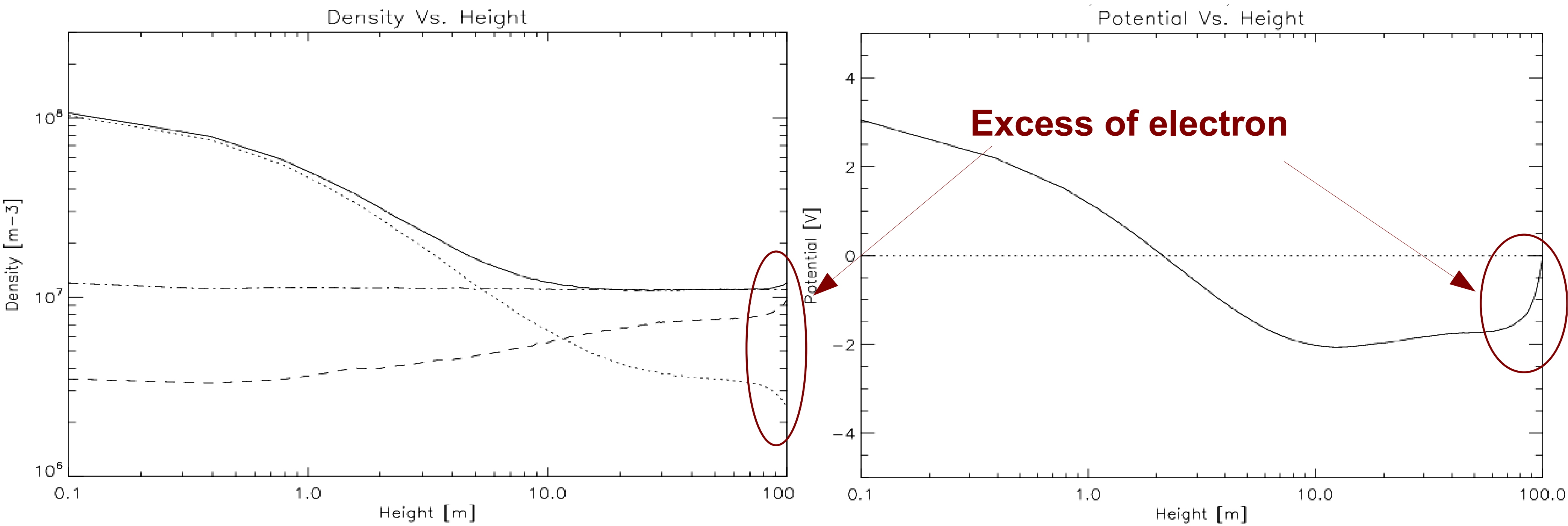
$n_i \approx n_{io}$

Solar wind e-: shifted Maxwellian same but $v_{te} >> v_0$

$n_e < n_{eo}$ ($n_e \neq n_i$)

Plasma Sheath and boundary conditions

Simulate the sheath above a surface in a simulation box with a single opened face.
Ex: Poppe et al, 2010



Excess of electron

Problem of plasma neutrality :

Truncated e- distribution : $n_e \neq n_i$

Photo-electrons

At top must have $n_i = n_e + n_\phi$

Solution : adapt n_{eo}

Solar wind ions: shifted Maxwellian $n_{io} \sim 10^7\ m^{-3}$

$v_{io} = 400$ km/s

$T_{io} = 10$ eV $(v_{ti} << v_0)$

$n_i \approx n_{io}$

Solar wind e-: shifted Maxwellian same but $v_{te} >> v_0$

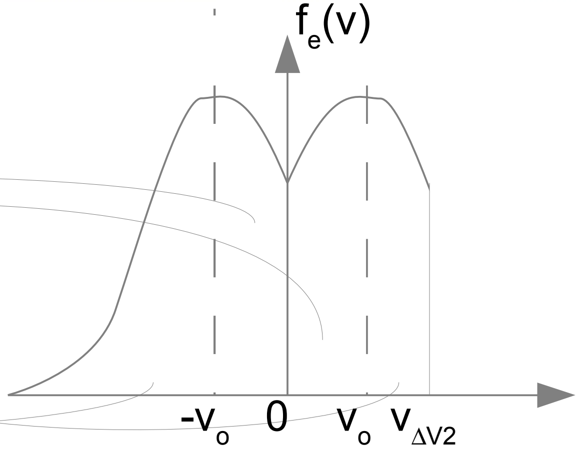
$n_e < n_{eo}$ $(n_e \neq n_i)$

Plasma Sheath and boundary conditions

Current at the potential minimum

$$n_{eo}=2\left(n_{io}-\Phi_{\phi}\frac{\exp\left(\frac{-e\Delta V_2}{kT_{\phi}}\right)}{e\sqrt{\frac{\frac{1}{\pi}kT_{\phi}+e\Delta V_2}{m_e/2}}}\right).\left(1+erf\left(\frac{v_o}{v_{Te}}\right)+erf\left(\frac{v_o}{v_{Te}}\right)-erf\left(\frac{v_o}{v_{Te}}-\sqrt{\frac{e\Delta V_2}{kT_e}}\right)\right)^{-1}$$

Photoelectron velocity at infinity



$$\Phi_{\phi}=\int J_{\phi}(\vec{n}.\vec{\sigma})\left(1-\frac{1}{\pi}acos(\vec{n}(\vec{x}).\langle\vec{n}\rangle)\right)\left(1-\frac{1}{\pi}atan\left(\frac{max(0,\langle\Delta V_1\rangle-\Delta V_1(\vec{x}))}{kT_{\phi}}\right)\right)\exp\left(\frac{-e\,max(0,\Delta V_1(\vec{x}))}{kT_{\phi}}\right)d\vec{x}$$

Sun direction

Effect of the surface orientation

Deviation of the electrons emitted over surfaces more negative than the average surface potential

Plasma Sheath and boundary conditions: Test Cases

Quasi-1D simulation box

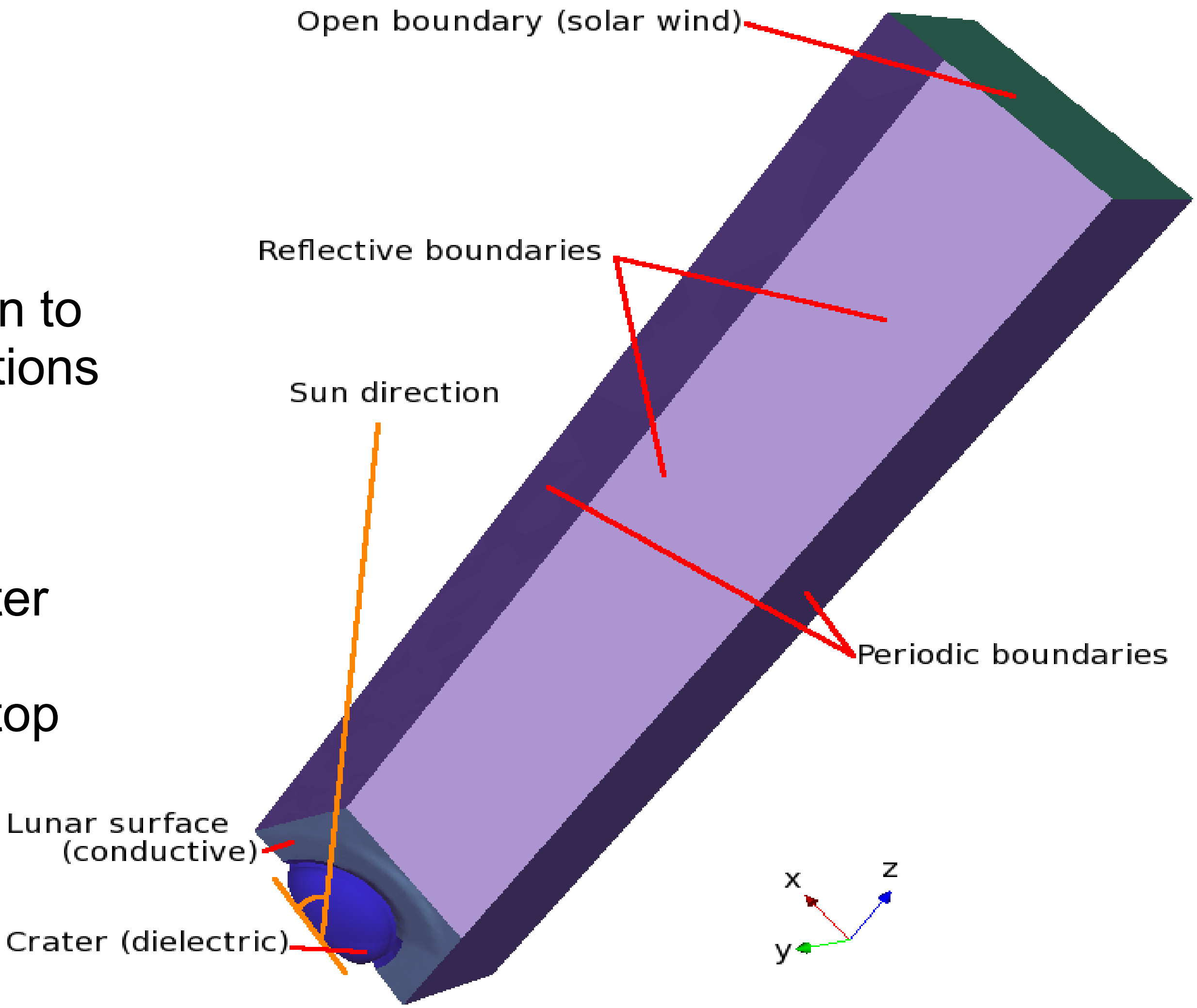
with a cratered dielectric surface

Periodic boundaries in one direction to allow for solar wind velocity inclinations (varies with SZA)

Reflective boundaries in the other direction ~> simulation of a full crater

Solar wind plasma injection at the top

No dusts at this stage



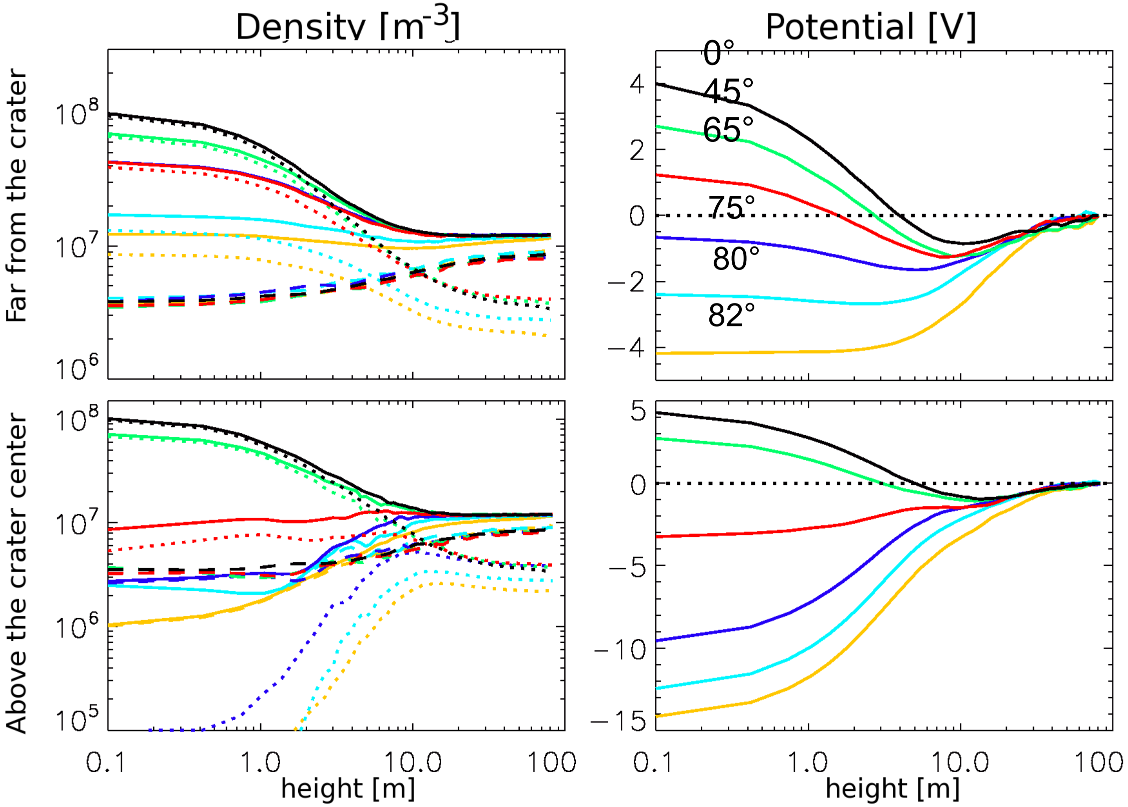
Plasma Sheath and boundary conditions: Test Cases

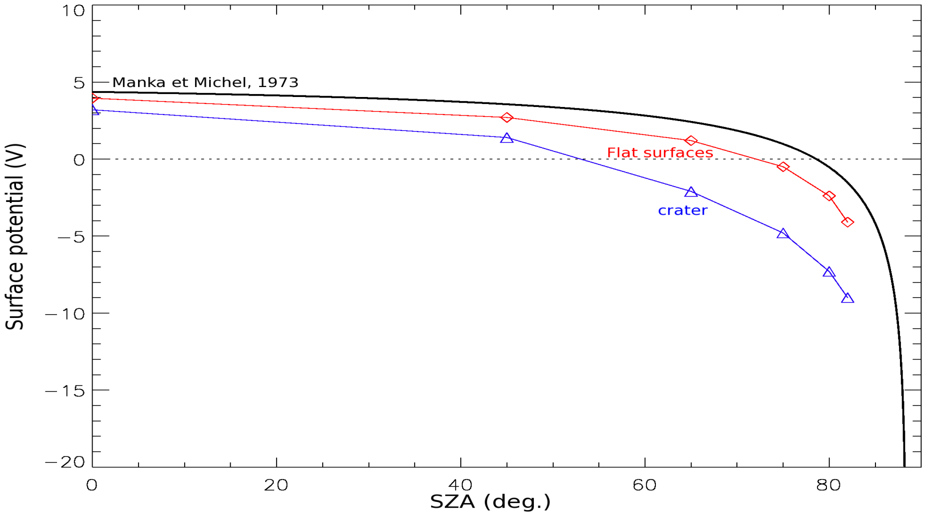
Simulations performed with
n_{sw}=12 cm^{-3}
v_{sw}= 400 km.s^{-1}
T_{sw}=10 eV
SZA = 0°, 45°, 65°, 75°, 80°, 82°

The potential goes smoothly to 0V above ~ 50 m

Density and potential profiles close to that found by Poppe et al. (2010).

Potential vs SZA consistent with Manka (1973) for flat surfaces, faster decrease in the crater





[Hess et al., in prep.]

Summary

Many new models and capabilities added.

New of experimental/observational data to determine the model characteristics

First step toward the simulation of dusty environments.

Some models can be used out of the dust context, such as the sheath model

New physics should be added to completely fill the needs for dusty environment description and interaction with the spacecraft.