return on innovation

SPIS-DUST

Extension of SPIS to simulate dust electrostatic charging, transport and contamination of lunar probes

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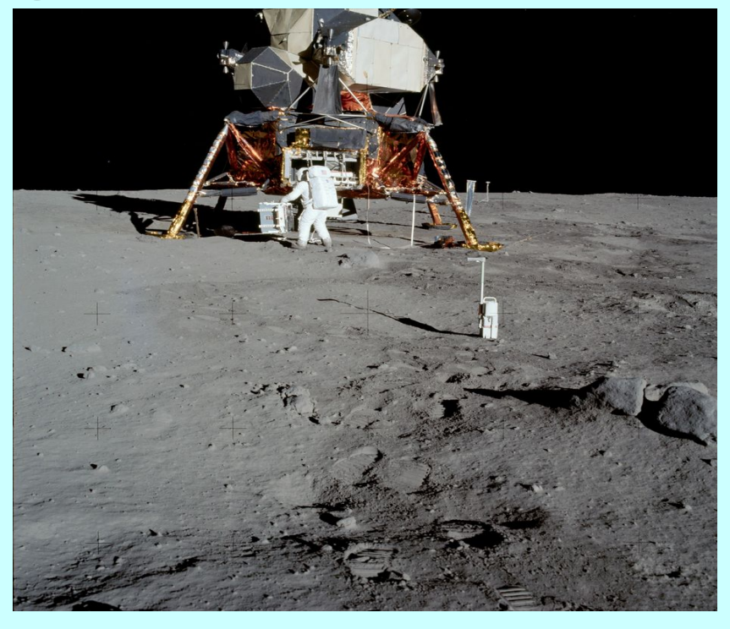
To simulate the lunar dusty environment challenges for exploration



US and Russian Lunar programs totalizing about 18 successful landings have experienced the harsh lunar environment, paving the way for future exploration mission.

The detrimental effects of dust on equipment and humans have been extensively reported. Lunar dust has been clearly identified as a concern for lunar exploration, specifically for long duration missions

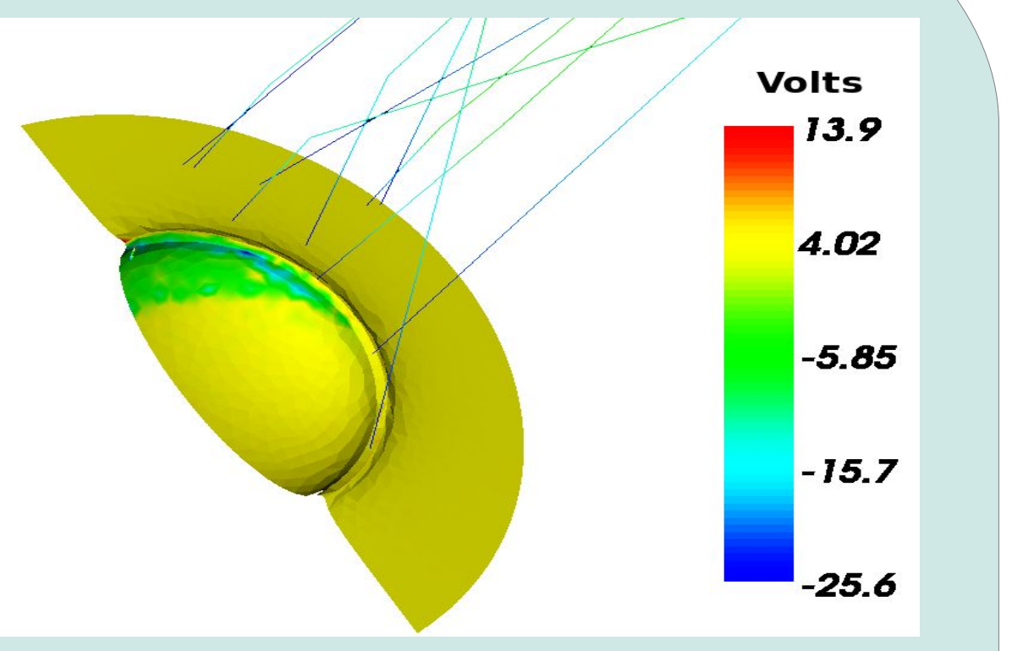
Objectives:

- To develop an engineering support tool allowing to simulate interactions between charged dust and exploration units surfaces in the Lunar environment under various plasma and illumination conditions.
- To provide relevant parameters to assess charged dust contamination and detrimental effects on sensitive surfaces (e.g. solar panels, optical surfaces,...) for future ESA exploration missions (e.g. Lunar Lander).

The ***Spacecraft Plasma Interaction Software*** is extended to handle the complex charging dynamic of a 4 component system : planetary surface – planetary dust - exploration unit – plasma, which requires :

- to build 3D geometrical models of portions of a planetary surface (including topological non-homogeneities) together with exploration units in contact with the surface.
- to define plasma environments and dust populations characteristics.
- to implement the physics of dust charging and transport in the Lunar environment in the SPIS architecture.
- to model charged dust separation from the planetary surface.
- to model dust – exploration unit interactions (triboelectric charging, adhesion,...).
- to provide first order dust contamination diagnostics (as dust coverage) for equipment exposed to the lunar environment.

Plasma conditions and sheath modeling



Surface potential in the simulation: the sun inclination is 45°

The dust dynamics may evolve depending on the solar lighting and on the plasma conditions at the moon surface.

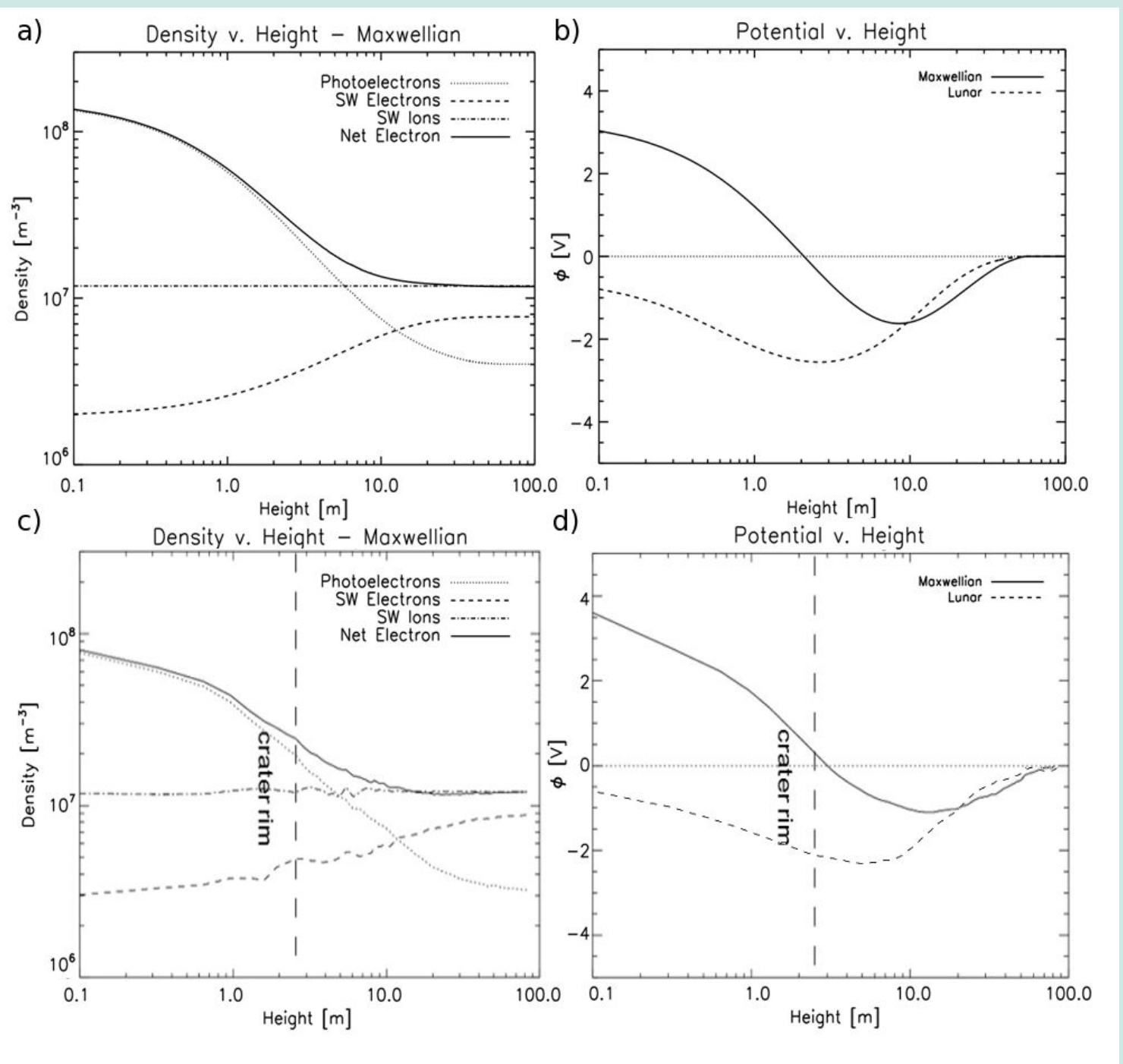
Different parameters sets have been predefined that allows to simulate the lunar surface when the moon is in the solar wind, in Earth's magnetosphere and in the plasma sheet.

The dust levitation is strongly dependent on the potential profile just above the surface, which is determined by the photo-electron sheath.

The modeling of the sheath requires an accurate tuning of the plasma conditions at the boundary, which is difficult to obtain in a quasi-1D scenario.

In SPIS, the solar wind electron flux at the open boundary n_{e0} is automatically scaled to ensure quasi-neutrality at infinity:

$n_i - n_{p\infty} = \frac{n_{e0}}{2}\left(1 + 2\,\mathrm{erf}\left(\frac{v_d}{v_{Te}}\right) - \mathrm{erf}\left(\frac{v_d}{v_{Te}} - \sqrt{\frac{e\Delta V_{dip}}{kT_e}}\right)\right)$	Quasi neutrality condition
$n_{p\infty} = \frac{\Sigma_{i\in surface} J_{pi} a_i b_i c_i d_i S_i}{-e v_{p\infty} A}$	Photo-electron density at ∞
$v_{p\infty} = \sqrt{\frac{\frac{2}{\pi} kT_{p+e\Delta V_{dip}}}{m_e/2}}$	Photo-electron velocity at ∞
$a = exp\left(\frac{-\max\left(0, e\left(V_{surf} - V_{dip}\right)\right)}{kT_p}\right)$	Effect of the potential barrier
$b = (\vec{\varphi}.\vec{n})$	Effect of the sun inclination
$c = 1 - \pi^{-1} acos(\vec{n}.\langle\vec{n}\rangle)$	Effect of the surface inclination
$d = 1 - \pi^{-1}\mathrm{atan}\left(-\frac{max\left(0, e\left(\langle V_{surf}\rangle - V_{surf}\right)\right)}{kT_p}\right)$	Effect of the surface differential potential



Density and potential profiles for Poppe et al. 2010 and our simulations. Given the differences in the boundary conditions and geometry, the results are similar.

Dust charging, emission, transport and interactions with the Plasma and spacecraft

Dust charging on surface

The charge on a surface element is given by the Gauss theorem: $Q_S = \epsilon_0 E_S S$

It is divided between all the macroparticles: $\Sigma_N \bar{w} \bar{Q}_D = Q_S$

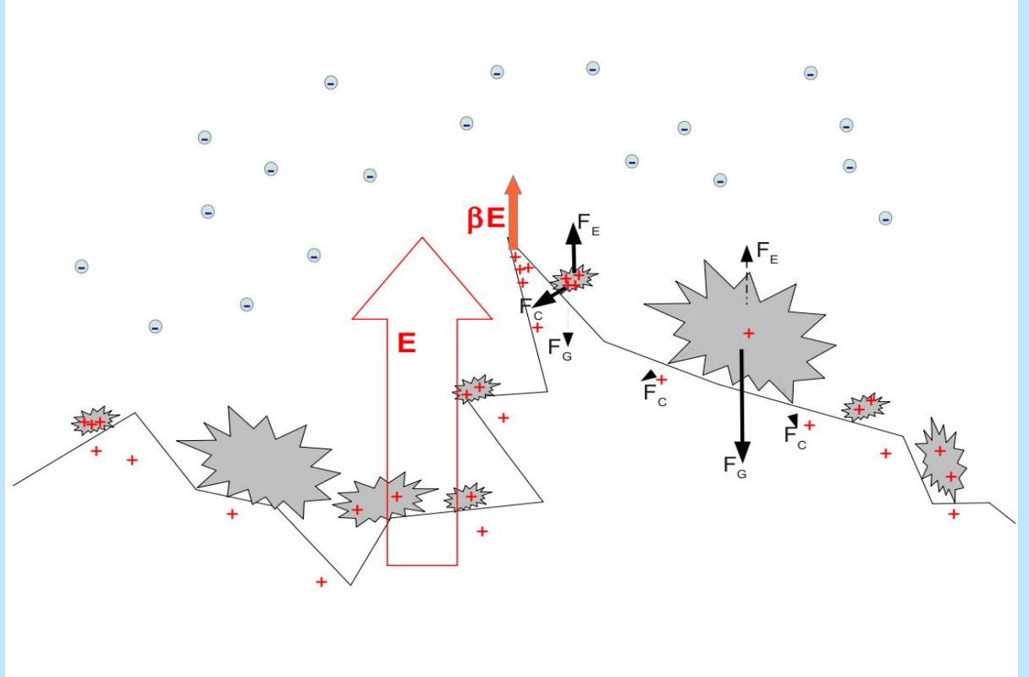
The charge is not equally divided between all macroparticles but depends on the particles radii, following:

$$\bar{Q}_D = CV \; with \; C = 4\pi\epsilon_0 r_D$$

The charge is neither equally divided between the physical particle within the macroparticles, but only on a fraction of them:

$$Q_D = \beta\bar{Q}_D \quad \text{and} \quad w = \frac{\bar{w}}{\beta}$$

Dust emission and charge after emission



The dust lift off is controlled by the force balance, it includes

gravitational force: $\vec{F}_G = m_D(\vec{g}.\vec{n})\vec{n}$

user defined seismic acceleration, $\vec{F}_s$

cohesive forces: $\vec{F}_C = -KS^2 r_D \vec{n} \; where \; KS^2 = 10^{-6} kg/s^2$

and electrostatic forces: $\vec{F}_E = \beta Q_D(\vec{E}.\vec{n})\vec{n}$ where β stands for the microscopic electric field amplification.

When the dust is emitted its charge is computed assuming that it has the same potential than the ground. Then, a triboelectric charge is added: $Q = CV + [Q_0 + Q_r * r_D + Q_w * W + Q_{rw} * W * r_D]$ with W the surface material work function and with parameters obtained from Sternovsky et al. 2002.

Dust transport and charging in the volume

The dust motion is dictated by the same forces than plasma species plus the photon pressure, computed taking into account the dust cross-section and the volumetric shadowing.

The charges of the dusts evolve along their trajectories as they collect plasma electrons and emit secondary and photo electrons: $\frac{\Delta Q_D}{\Delta t} = J_c + J_s + J_\varphi$

The collected electrons are computed using OML and/or Monte-Carlo models and the dust potential:

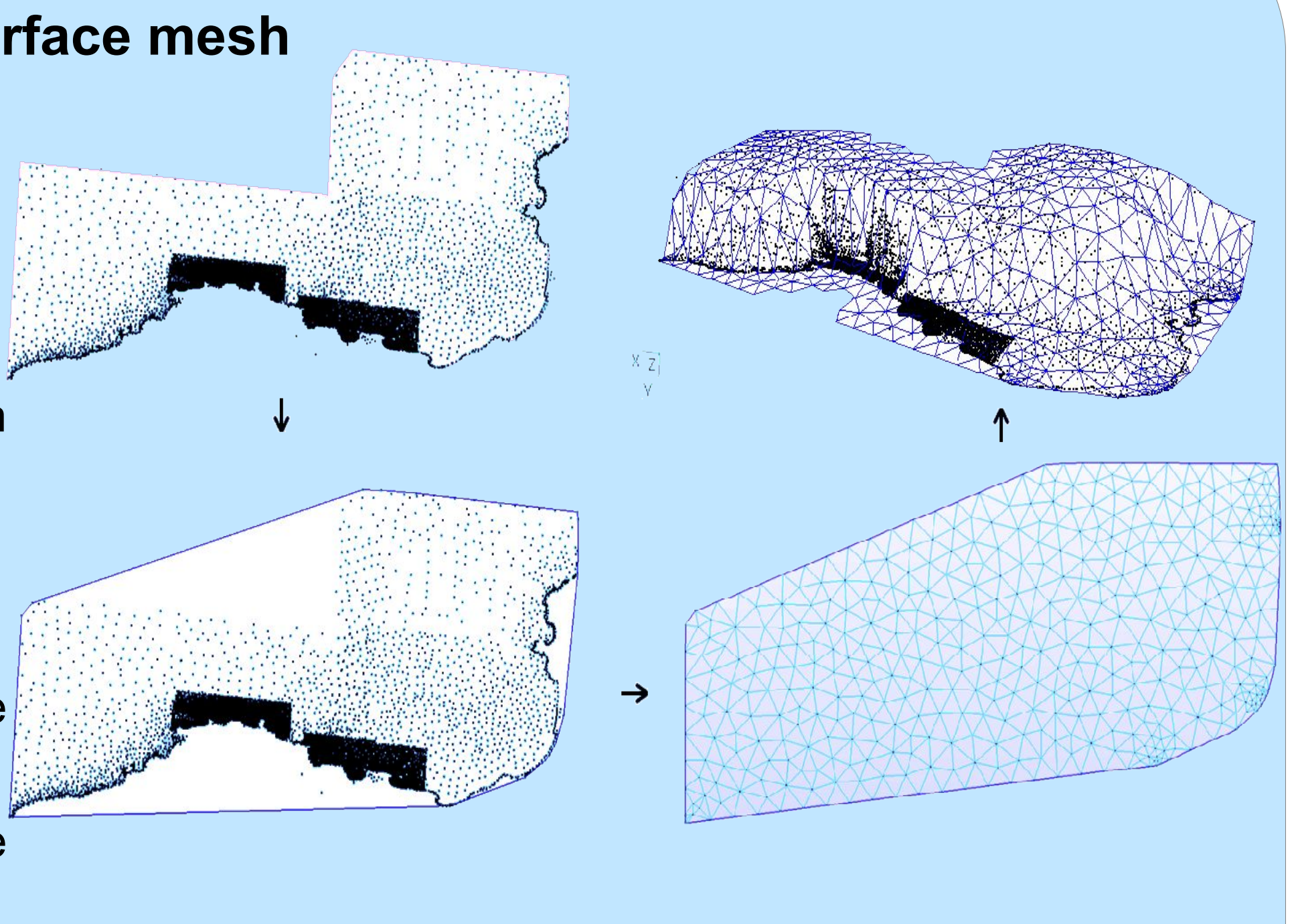
$$V_D(t) = \frac{Q_D(t)}{4\pi\epsilon_0 r_D(1 + r_D/\lambda_D)}$$

Secondaries are computed from the electron collection and a yield function given by the model of Chow et al. 1993. Since solving the equation of this model is computationally demanding, the solutions are precomputed at the beginning of the simulation.

Photo-electrons are emitted with a distribution following the Feuerbacher, 1972 measurements with the flux dependance on the dust potential (recollection) taken into account.

User Interface improvement and addition of new features

From sets of geographical coordinates to surface mesh



SPIS-DUST offers the possibly to either:

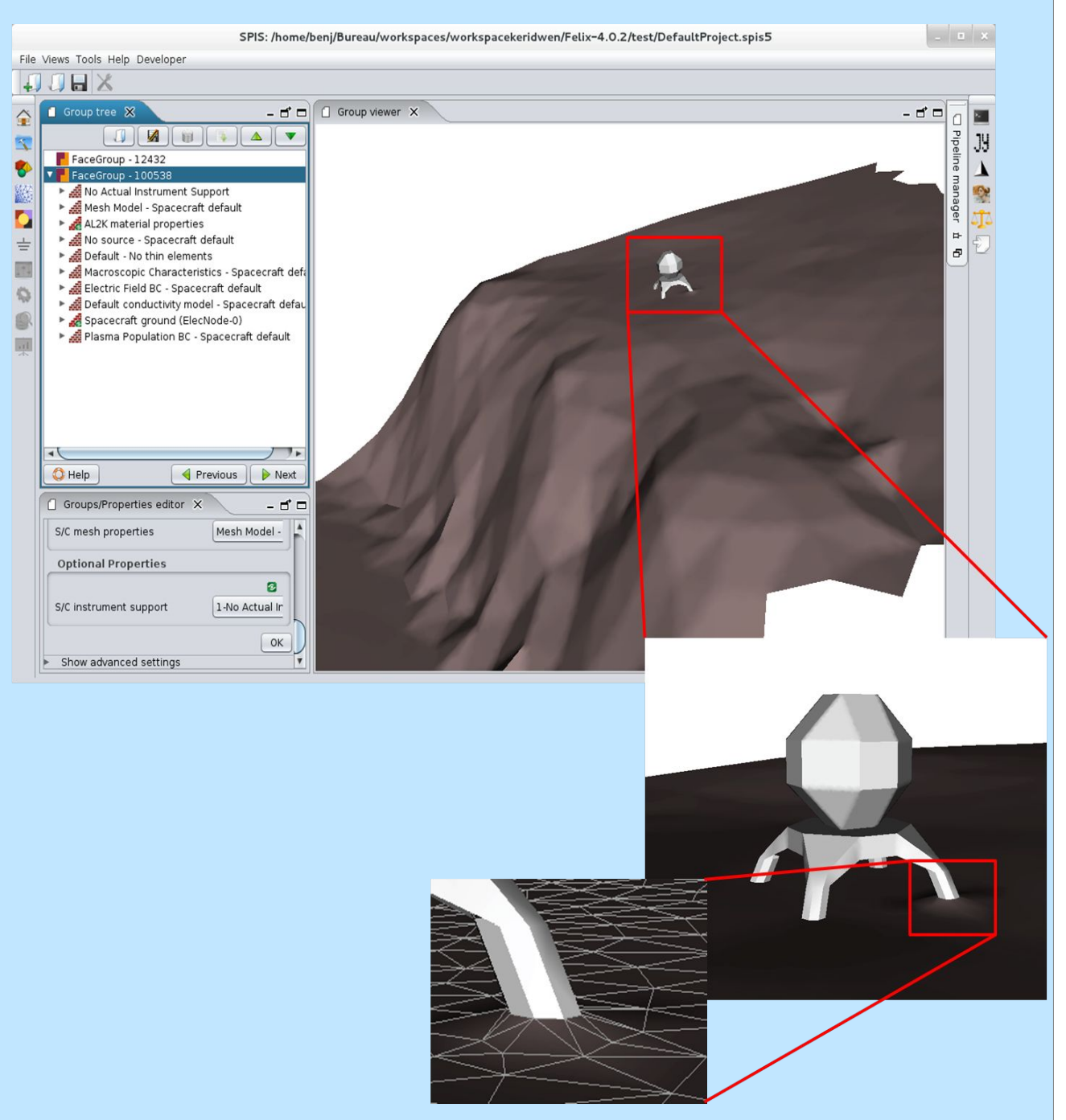
explore the parameter space using hand-made geometry

prepare a mission by importing a real terrain geometry

In the latter case, the SPIS-DUST UI eases the simulation mesh generation by :

- importing terrain coordinates
- automatically computing the surface borders
- meshing the surface and determining the surface elevation by Kriging.
- performing extrusion along altitude axis to generate the simulation volume.

Insertion of a spacecraft and merging with the surface mesh



SPIS-DUST UI offers the possibility to insert a CAD model of a spacecraft in the computational volume.

New algorithms ease the merging of the spacecraft and lunar surfaces, still offering to the user control over the merging process. The UI detects facing surface elements and merges those selected by the user in a way satisfying SPIS computational requirements.

Lunar surface and dust material properties

New material properties are defined for dusty surfaces, that are transmitted to the dusts particles emitted in the simulation volume, in particular:

- dust radius distribution. Predefined distribution extrapolated from data in Heiken, G., Vaniman, D., & French, 1991.
- dust secondary yield parameters for the Chow et al. 1993 model.

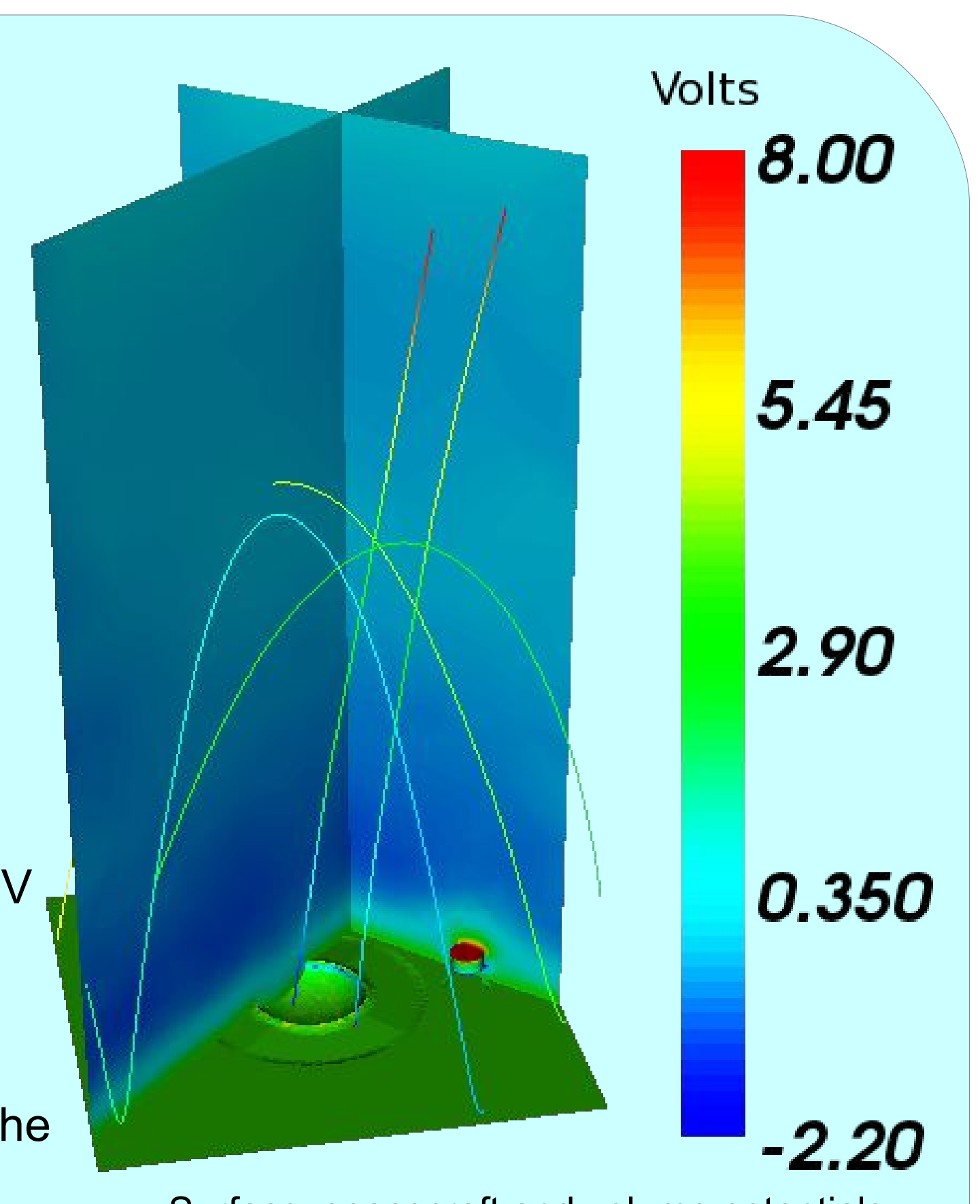
Two sets of lunar soil parameters have been predefined that correspond to lighted conductive lunar soil and shadowed dielectric lunar soil.

New dust dedicated instruments

New result outputs ("instruments") dedicated to the dusts and their interaction with the spacecraft are implemented:

- dust detector
- dust distribution sensor
- dust trajectory sensor
- high altitude (above the simulation domain) dust profiles
- surface obscuration by dust, dust layer thickness,...

Test case results



Surface, spacecraft and volume potentials and some dust trajectories (for which color stands for time)

We present here results from a test case simulation performed assuming:

- a 60 m x 60 m x 80 m simulation domain
- a 10 meter wide, 2 meter deep crater in the center
- a 3 meter wide cylindrical probe with three 2m long feet
- a zenithal solar direction
- n_i=12cm^{-3} (n_e from the electron scaler ~11.3cm^{-3}), v_{sw}=400m/s, T_{sw}=10eV

The lunar soil is assumed conductive except for the crater.

The spacecraft body is in aluminium, except for the top (solar panel) and the bottom (Kapton).

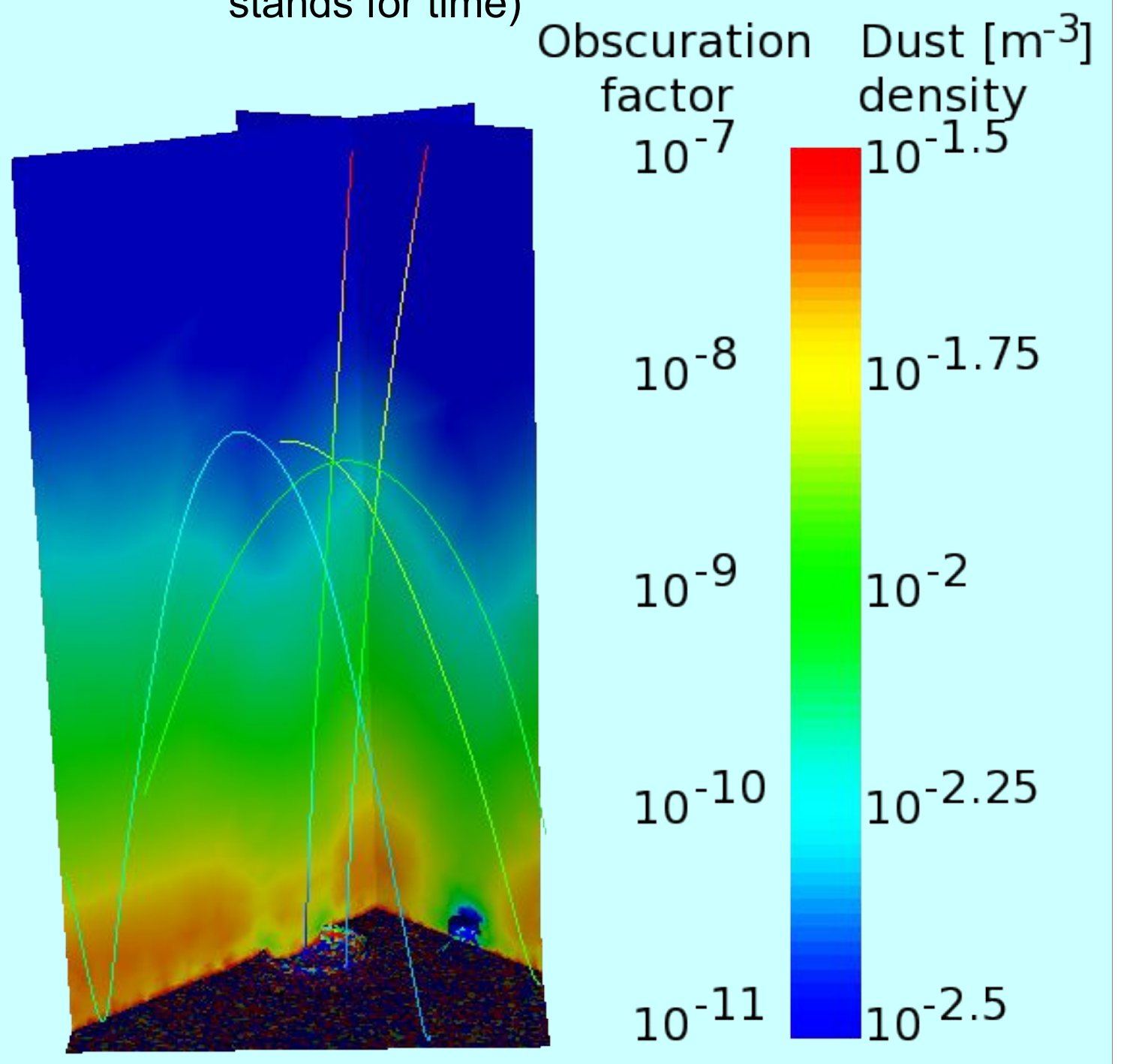
This set up is relatively safe for the spacecraft:

The soil and dust charge positively, but ~ uniformly
(little surface differential charging ⇒ low E ⇒ low dust emission)

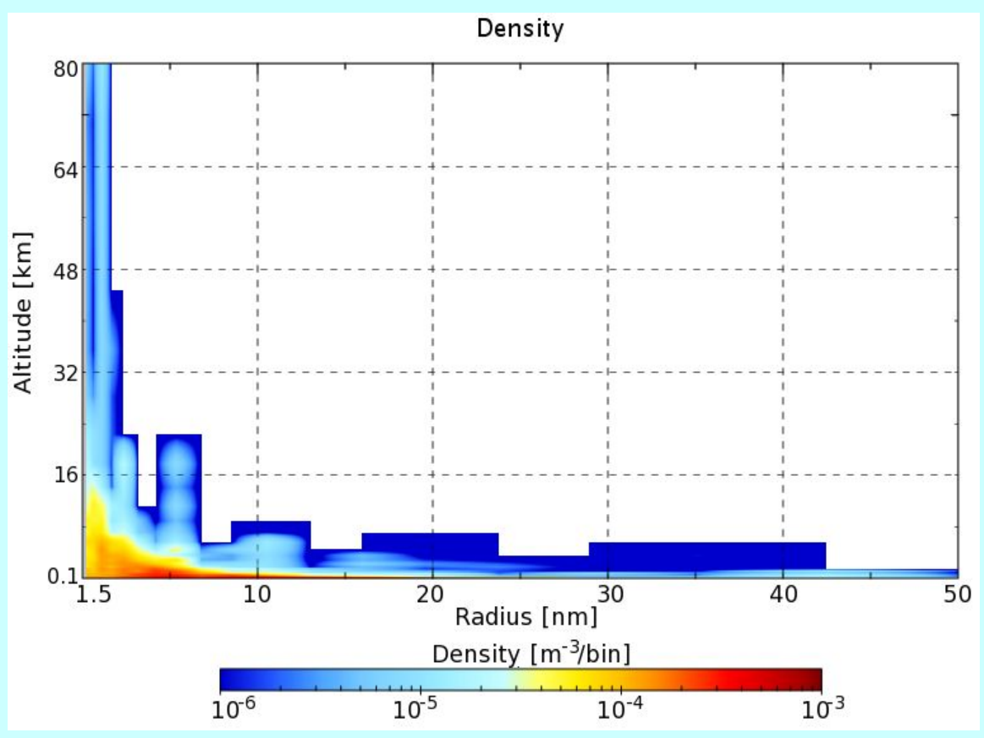
The solar panel also charges more positively than the dusts
(no dust collection on the solar panel)

More challenging situations are found when changing the geometry, in particular the solar inclination.

Nonetheless, dusts are emitted to high altitudes and the spacecraft body collects dusts.



Dust density in the volume and surface obscuration factor (fraction of the surface covered) after 500 s. Probe top is assumed dielectric (cover glass) and charges positively, repulsing dusts, whereas the dielectric bottom (Kapton) charges negatively and collects dusts.



Dust density versus altitude and radius above the simulation domain extrapolated by computing the dust trajectories and assuming constant dust charges.

Acknowledgments

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