Lunar Dusty Plasma Environment: A 3D Simulation

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Abstract


Figure 1: The lunar surface

Dust particles are present in almost all space environments, including the ionosphere, interplanetary space and large celestial bodies. In lunar missions, dust reduces material lifetime due to adhesion and abrasion, optical visibility due to dust levitation, causes astronauts health hazards and contaminates solar panels.

A 3D simulation code has been developed to study dusty plasma environments such as the lunar dusty exosphere.

The software simulates lunar surface charging and dust levitation. Our simulations demonstrate that the dynamics of lunar dust are region-dependent. Low surface electric potential on the dayside creates weaker electric fields compared to, for example, the terminator region. As a result, lunar dust rises only a few centimetres on the dayside but several hundred metres near the solar terminator. As a result, dust particles will engulf a lunar exploratory vehicle rover in the solar terminator region but move outward from the vehicle when it is on the dayside. Similarly craters on the dayside will attract dust to their centre whilst repelling dust when in the solar terminator region.

Simulation of Dust Charging and Levitation

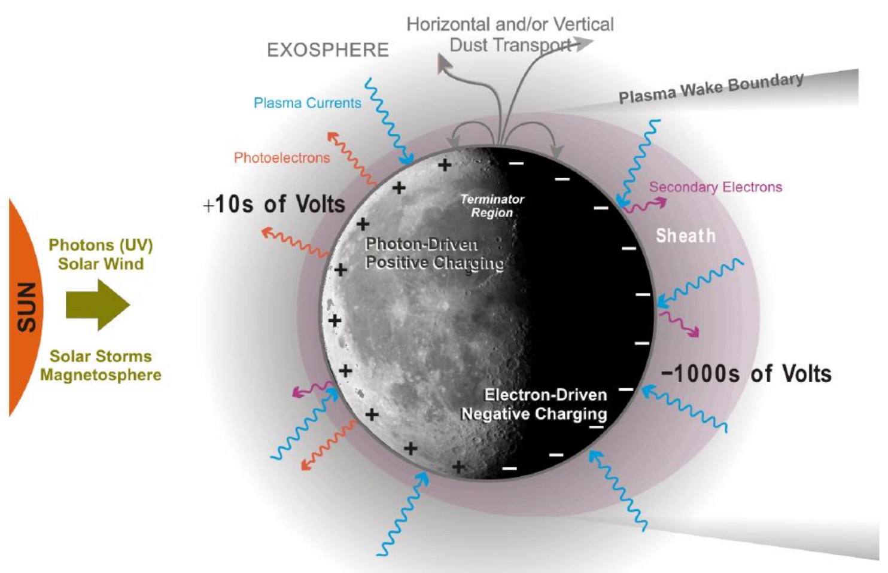

Figure 2: Solar ionisation and charging

A new SPIS-Dust 3D simulations code has been developed based on Spacecraft Plasma Interaction System (SPIS). The code is capable of simulating:

1. Dust charging
2. The lunar dust levitation process
3. Dust dynamics in the presence of a lunar rover.

- A 'Particle in cell' method describes particle dynamics, considering electrostatic and gravitational forces.
- 'Monte-Carlo' techniques are used to simulate collisions and dust charging in an ambient plasma.
- The model is applicable to dust-in-plasma and dusty plasma systems.
- The model considers parameters of the solar wind, the solar flux incident angle, photoionisation and ionisation by secondary 'photoelectrons'.

Modelling of the maximum levitation heights for dust particles of radius 50, 100 and 500 nm are shown in Figure 3 (below) as a function of particle charge/mass ratio. This ratio must exceed 0.6 for any levitation to occur. This occurs for a surface potential of approximately -57 V.

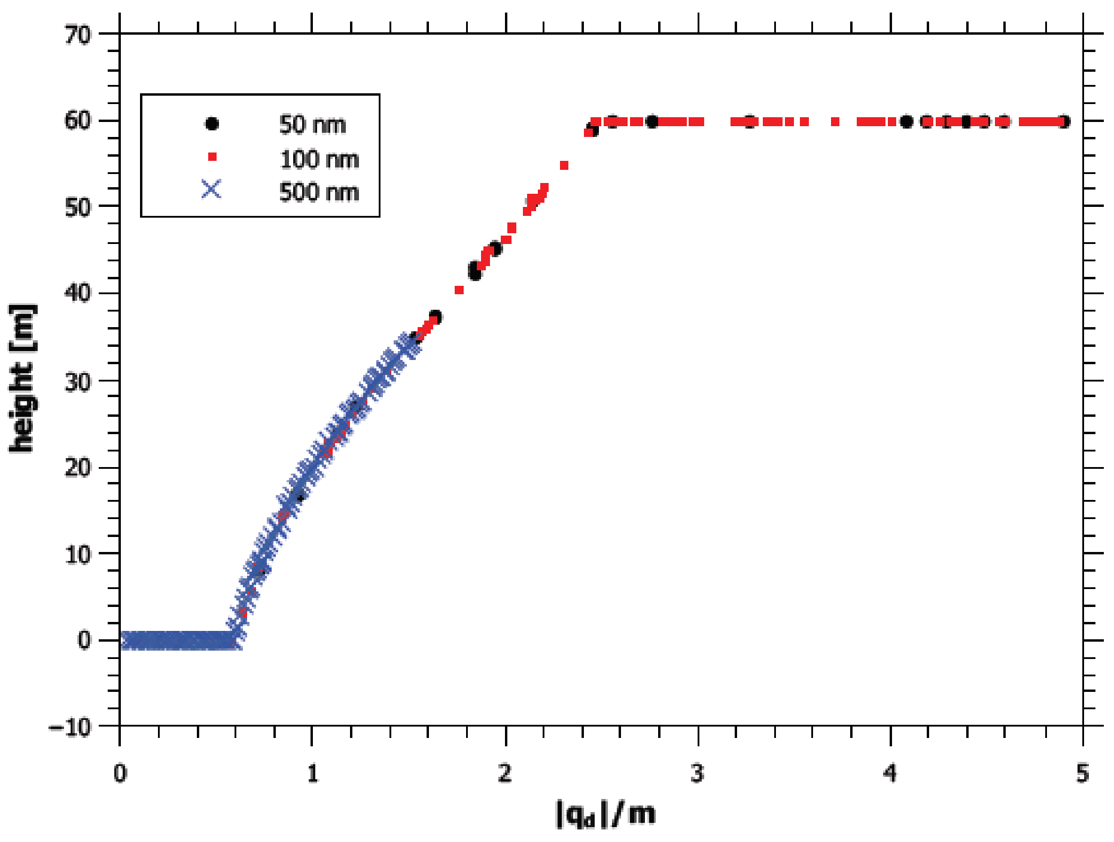

Figure 3: Maximum levitation heights of dust particles of three different radii as a function of the charge/mass ratio. The simulation domain was limited to 60 m height

Time-varying charge distributions may also be simulated around dust clouds suspended in an ambient plasma. Figure 4 (below) presents an example for a particle density of 10^8 m^{-3} and Debye length, λ_D = 1.05 x 10^{-2} m typical of an ionospheric plasma.

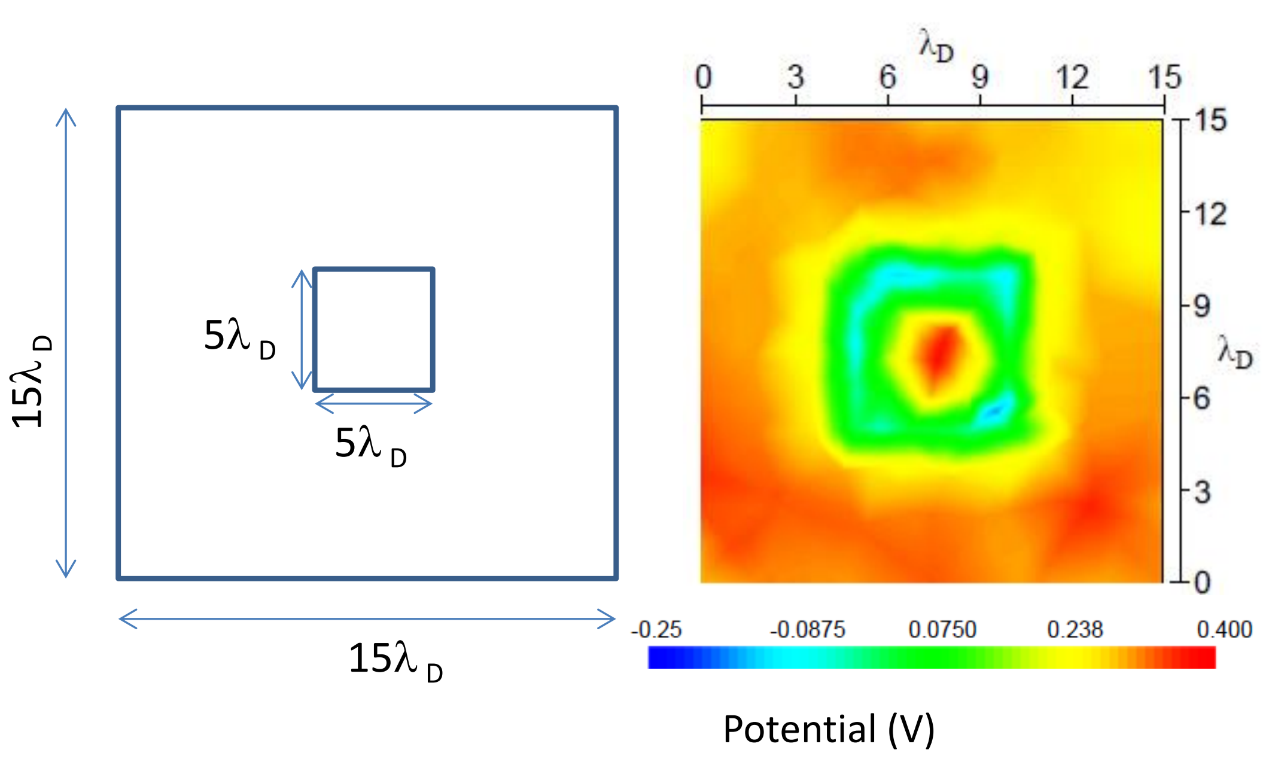

Figure 4: (Left): Model of dust cloud (confined in central square) within an ionospheric plasma. (Right): Simulated electrical potential distribution for a particle density of 10^8 m^{-3}.

Dust Dynamics in the Vicinity of a Crater

Figure 5 (right) presents simulations of electric potentials in a 5m diameter 1m deep crater for four solar flux directions, θ (indicated by the arrows). Surface charging depends on the surface illumination and exposure to the solar wind. At the terminator (θ = 90°) a high positive potential is observed on the side facing the solar wind with a negative potential on the shadowed side.

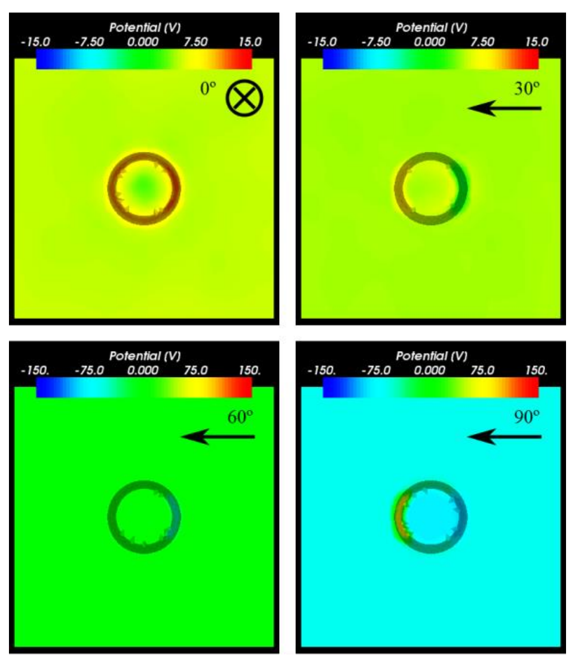

Figure 5: Charge distributions about a lunar crater.

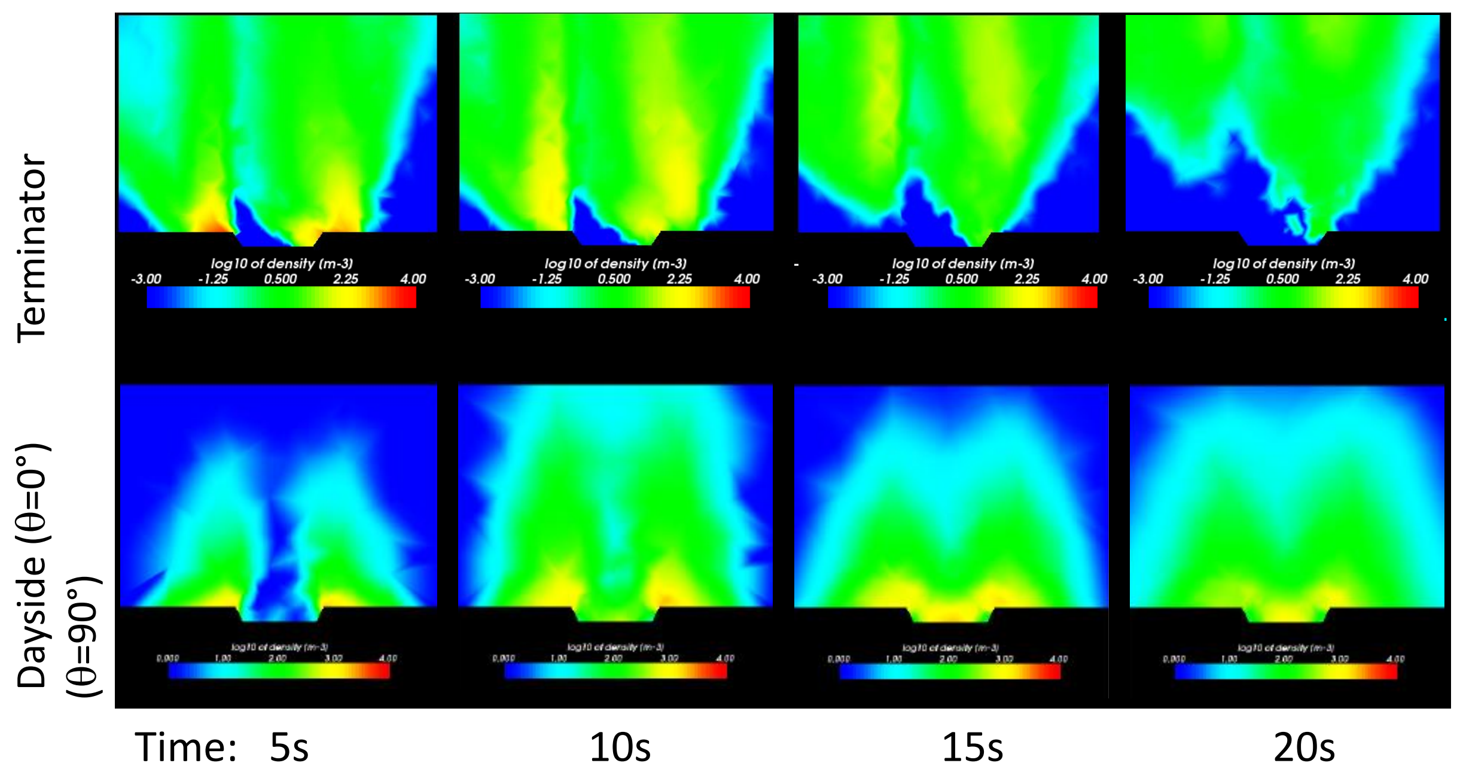

Figure 6: Dust distributions about a lunar crater.

Figure 6 (above) presents time-sequence simulations of the release of dust outside the rim of a lunar crater. At the terminator (top panels) the presence of strong negative electric fields repels dust particles, preventing them from reaching the basin of the crater. On the dayside (bottom panels) dust is attracted towards the middle of the crater basin.

Lunar Rover Dust Simulations

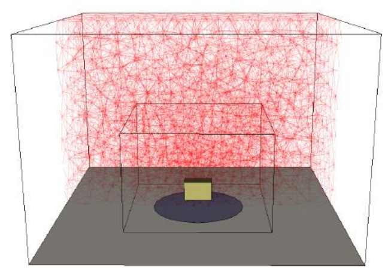
Figure 6: The lunar rover model.

The lunar rover is simulated as a 3m x 1.5m x 2 m cuboid, suspended 1 m above the lunar surface.(see Figure 6 (left)).

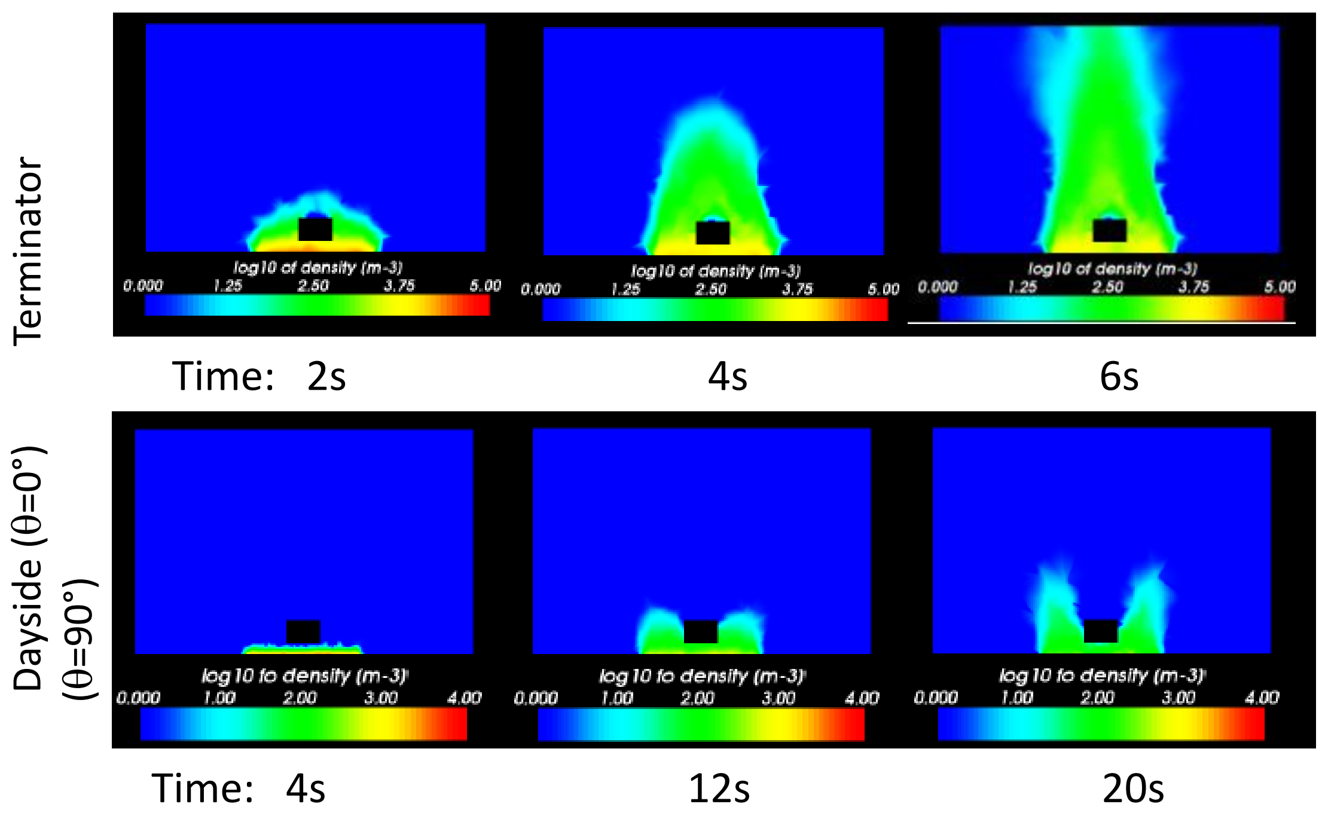

Figure 7: Dust distributions about the lunar rover.

Figure 7 (above) presents two time sequence simulations of dust density around the lunar rover model. In the terminator region (top panels) dust accumulates above the vehicle, whereas on the dayside, the dust accumulates to the sides of the vehicle.

Conclusions

The Spacecraft Plasma Interaction System has been developed to study:

1. The dust charging process
2. Dust dynamics
3. Dust dynamics near charged objects

Simulations indicate that on the lunar surface, dust levitation occurs when the charge/mass ratio exceeds 0.6, requiring a surface potential of approximately -57 V.

Further simulations demonstrate that dust movements around craters or a charged lunar rover depend on the angle of solar illumination, with large differences observed between dayside and terminator regions.

Acknowledgements

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