Dusty Plasma Environments: Near-Surface Characterisation and Modelling

Executive Summary Report

September 2014

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Contributors

Jean-Charles Matéo-Vélez
Sébastien Hess
Pierre Sarrailh

ONERA/DESP
2 Av. Edouard Belin
31055 Toulouse cedex
France

Verified by

Virginie Inguimbert **ONERA/DESP**

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Objectives

The NEMS – Near-Earth Exploration Minimum System internal ESA study, conducted at ESA's Concurrent Design Facility (CDF) between March and April 2011 aimed at investigating and reporting on the main trade-offs, system drivers and critical risk areas associated with even the most basic human exploration beyond Earth-Moon system. The (purely theoretical) mission scenario addressed the transfer a crew of 3 astronauts from the Earth to an accessible Near-Earth Asteroid (NEA) and their safe return to Earth before 2030. Dust contamination was identified as a major concern.

The present activity was launched under a General Studies Program ESA funding to specify the plasma and dusty environments around solar systems objects including the Moon and asteroids. The final goal was to propose a numerical model of plasma, object and dust interaction able to provide information on dust distributions above these objects of interests.

The work was divided in the estimation of harmful effects for landing missions, review of existing work, development and test of the numerical tool, and finally analysis of gaps and definition of a road map for future activities.

1. HARMFUL EFFECTS

The Apollo mission reports are the best resources available for dust effects as they are the only eyewitness accounts to date. A wealth of knowledge can be gained from these missions. The Apollo astronauts experienced several effects from the dusty lunar environment: vision obscuration, false instrument readings, dust coating and contamination, clogging of mechanisms, abrasion, thermal control defects, seal failures, health hazard including skin, eye and nasal passage irritancy. Post mission tests estimated that particles decrease in size to 5µm or less would penetrate deeper into the lung and bronchioalveolar regions with symptoms such as edema, inflammation, brosis, and potentially carcinogenic effects.

2. DUSTY ENVIRONMENT MODEL

The analysis of the observations, laboratory tests and numerical models from the literature led to the definition of physical and numerical model requirements divided in four areas: ambient environment model at mesoscale (typically hundreds of meters), object surface charging, soil dust charging and ejecta models, dust transport in the plasma phase.

The dust size distributions were taken from the Lunar Source Book. Models for their electrical properties (secondary electron emission yield under electron impact, photoemission, conductivity) were estimated from adjacent research areas (dusty plasma physics mainly).

The numerical model for the plasma sheath modelling has shown to be efficient in the 1D and 2D approaches considered in this work. Efforts were dedicated to propose and implement a generic method for the ambient electron injection, which satisfies the plasma quasi neutrality far from the object, even in case of strong electron emission by the surface (typically photoelectrons). The automated computation of the influx of electrons permitted to avoid unphysical potential structures at the open boundary which would have otherwise compromised the accuracy of the modelling.

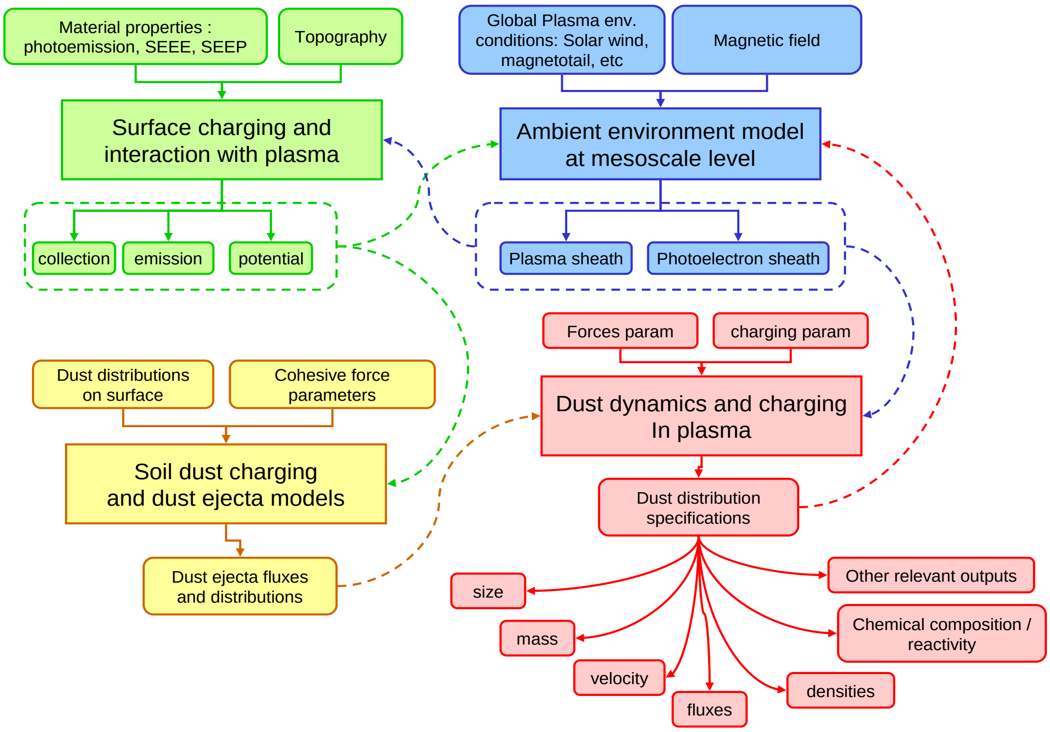

Figure 1 - Overview of dusty environment physical modelling

Dust charging on the ground was computed self-consistently using Gauss law and assuming spherical dusts. Electric field amplification at the surfaces occurs due to microscopic irregularities of dust shapes and dust layer geometry, including shade effects. Dust emission was computed by calculating the force balance on a sampled set of radiuses. The forces considered on the surface were: gravity, electrostatic forces at large scale (though microscopic with the β enhancement factor) and at smaller scales (cohesive forces) and seismic forces. A Monte Carlo Collision method was specifically designed for the dust charging in plasma. It included ambient particle collection as well as secondary electron emission and recollection. The dust charge and potential were then used to compute the feedback loop on the plasma (as for instance electron depletion). As a whole, the proposed model covered all important aspects of the physics to be modelled. In addition, monitors of dust characteristics outputs included dust moments in the 2D domain as well as information along particle trajectories (potential, dust charge and velocity, ...). The tool offered a detailed view of the dusty environment characteristics, from the surface to some hundreds of meters above.

3. DEFINITION OF LUNAR AND ASTEROID DUSTY ENVIRONMENTS

A large set of numerical simulations were performed for the Lunar surface (more than 20 studies) and an asteroid having the characteristics of (101955)Bennu and (25143)Itokawa in solar wind condition. It included Solar Zenith Angle (SZA) variations from 0° to 80°, flat surfaces and craters. Plasma sheath results showed a good behaviour; see for example the photoelectron density profile above flat and crater surfaces of the Moon in Figure 2. Comparison with existing works was satisfactory.

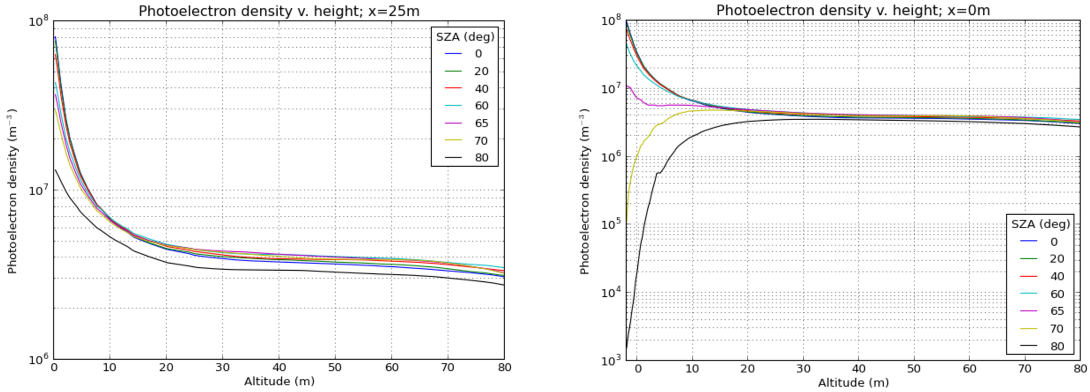

Figure 2 - Photoelectron density profiles versus altitude on the Moon, above a flat surface (left) and above a crater centre (right)

Figure 3 is an illustration of the model capabilities to compute the plasma and dust behaviour around a medium size asteroid typical of Bennu and Itokawa, with the presence of craters at different SZA. Non uniform surface charging leads to different dust ejection characteristics, especially at the edge of the craters. Dust transport is limited to a few meters at the Terminator because the dusts getting positive in the plasma due to photoemission are re-attracted back by the negative surface potential. At normal incidence angle, the surface being slightly positive, dusts are ejected on larger scales. This may be the reason why horizon glows were observed during the Apollo missions.

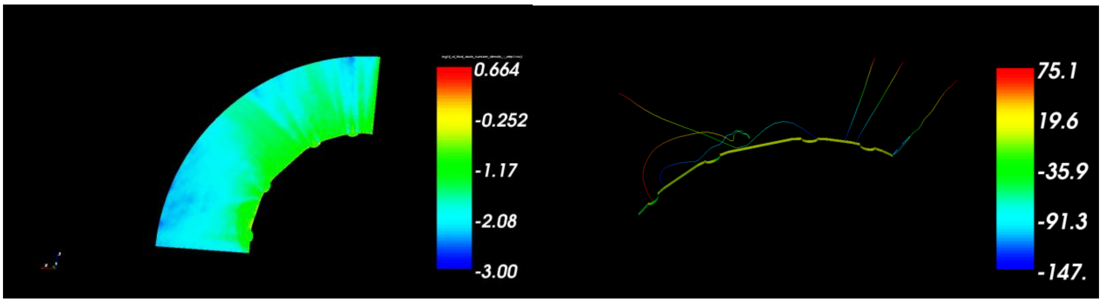

Figure 3 - Dust number density (log scale – left) and a few selected dust trajectories (right) above an asteroid surface (a quarter of it being simulated)

4. GAPS ANALYSIS AND ROADMAP

While the model is satisfactory to catch the global physics of dusty environments, detailed gaps in knowledge and numerical modelling were identified. It concerned the link of this mesoscale level, i.e. at the length scale of a few centimetres to some tens or hundreds of meters with the macro and microscopic scales. Coupling the tool with large scale simulations of the plasma sheath around the Moon would provide better inputs for more complex situations such as different plasma conditions and at shade for instance. The microscopic scale interactions of dusts at the Moon or asteroid surface would require conducting experiments dedicated to generate relevant dust stimulants, test their electrical properties under space like conditions and determine the conditions for their migration due to electrostatic and mechanical stresses.