A DYNAMIC FOUNTAIN MODEL FOR DUST IN THE LUNAR EXOSPHERE.

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Introduction: During the Apollo era of exploration it was discovered that sunlight was scattered at the terminators giving rise to “horizon glow” and “streamers” above the lunar surface [1,2]. This was observed from the dark side of the Moon during sunset and sunrise by both surface landers and astronauts in orbit (Fig.1). These observations had not been anticipated since the Moon was thought to have a negligible atmosphere or exosphere. Subsequent investigations have shown that the sunlight was most likely scattered by electrostatically charged dust grains originating from the surface [2,3,4,5,6]. This dust population could have serious implications for astronomical observations from the lunar surface [7] and future exploration [8].

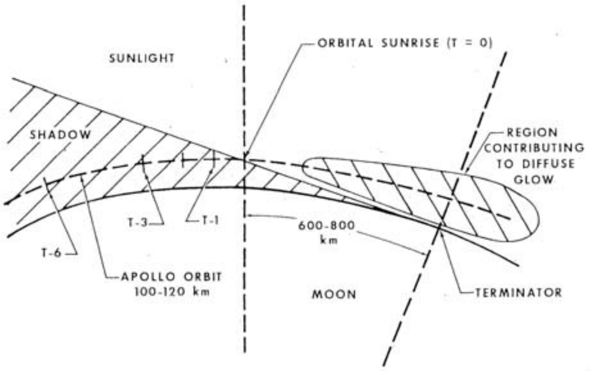

Fig. 1. Schematic showing a cross-section of the Moon in the plane of the Apollo orbit (dashed line). This depicts the physical situation consistent with Apollo 17 observations of “horizon glow” and “streamers” [1].

The lunar surface is electrostatically charged by the local plasma environment and the photoemission of electrons by solar UV and X-rays [8]. Under certain conditions, the like-charged surface and dust grains act to repel each other, such that the dust grains are ejected from the surface [2,3,4].

A dynamic “fountain” model has recently been proposed, as illustrated in Fig. 2b, to explain how sub-micron dust can reach altitudes of up to ~100km [10,11]. Previous static dust levitation models focused on heavier micron-sized grains near the surface, which did not explain the presence of much lighter grains at higher altitudes. By relaxing the static constraint, [10] showed that grains can be “lofted” to high altitudes under the action of dynamic forces. Here we aim to improve the dynamic fountain model by including more realistic electric field profiles [12] and new results relating to grain cohesion at the surface [13].

Apollo-era Observations: Horizon glow (HG) observed by the Surveyor-7 lander was most likely caused by electrostatically levitated ≈5µm dust grains at heights of ~10cm near the terminator [3]. HG observations were ~10^7 times too bright to be explained by secondary ejecta from micro-meteoroid impacts [2,3].

Astronaut observations of orbital sunrise revealed HG and streamers above the lunar surface (Fig. 1) varying on ~1–100s timescales. This indicated that they were produced by light scattering in the lunar vicinity by particles that were present sporadically [4]. The HG had a scale height of ~10km, so was unlikely to be caused by gases in the lunar exosphere [6].

The Lunar Eject and Meteorites (LEAM) experiment on the Moon detected the transport of electrostatically charged lunar dust [5]. The dust impacts were observed to peak around the terminator regions, thus indicating a relationship with the HG observations.

HG appeared as “excess” brightness in photographs taken from orbit of the solar corona above the lunar terminator. Excess brightness could not be accounted for by a co-orbiting cloud of spacecraft contaminants [1]. This evidence strongly suggested the presence of a variable lunar “atmosphere” of ~0.1µm dust extending to altitudes >100 km created by some electrostatic suspension mechanism [4,5].

Dynamic Dust Fountain Concept and Model: Fig. 2 shows a schematic comparing (a) the static levitation concept [1,2,3] with (b) the evolution of a dust grain in the dynamic fountain model [10]. In the levitation model the dust grain finds a point near the surface where the electrostatic (F_q) and gravitational (F_g) forces acting on it are about equal and opposite, and it is thus suspended. In the dynamic fountain model, once the dust grain has attained sufficient charge to leave the lunar surface (i.e., $F_q > F_g + F_c$), it is accelerated upward through a sheath region with a height ~λ_D (plasma Debye length). (Note: F_c is the force of grain cohesion at the surface.) The dust grains in question are so small that initially $F_q >> F_g$, such that the dust grains leave the sheath region with a large upward velocity (V_{exit}) and follow a near-parabolic trajectory back toward the lunar surface since the main force acting on them now is gravity.

Initial Results: Surface charging in the model is photo-driven on the dayside and plasma electron-driven on the nightside [8]. Fig. 3 shows the maximum height reached by a dust grain (Z_{MAX}) as a function of r_d and the angle from the subsolar point (θ) for typical solar wind conditions [10]. This suggests that dust can

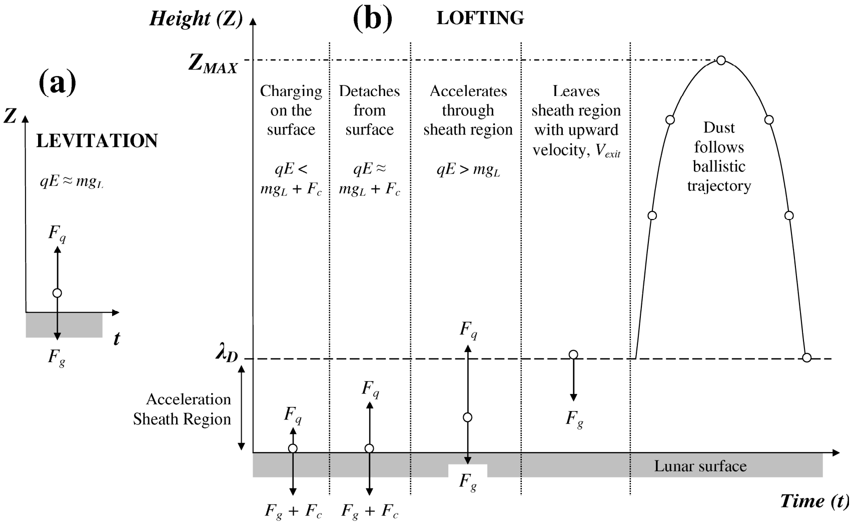

Fig.2. (left) Schematic comparing (a) the static levitation concept with (b) the evolution of a dust grain in our dynamic fountain model [10]. Forces on the grains: electrostatic (F_q), gravitational (F_g), and grain cohesion at the surface (F_c).

Fig. 3. (below) Spectrogram plot showing the maximum dust grain height reached (Z_{MAX}) as a function of angle from the subsolar point (θ) and dust grain radius (r_d) [10].

be lofted at most locations on the lunar surface, apart from in the region just sunward of the terminator labeled the “Dead Zone” ($\theta \approx 80°$), where the electrostatic surface potential $\phi_S \approx 0$. Fig. 3 also shows that at the terminator dust grains <0.1μm can be lofted to ~1–100km.

Discussion: In the model presented by [10] neglected effects included: (1) grain adhesion to the surface [14], (2) secondary electron currents [9,15,16], (3) realistic surface electric field profiles [12] and horizontal electric fields at the terminator [17], (4) the lunar wake electric fields near the terminator [18], (5) collective behavior on dust grain charging [16].

In order to improve the accuracy of this model we will include more realistic surface electric field profiles and grain cohesion at the surface. Inclusion of realistic surface electric field profiles [e.g., 12] is unlikely to affect the Z_{MAX} reached by the lightest grains; however, it will likely significantly increase the time-of-flight estimates. Grain cohesion at the surface is anticipated to limit dust transport for surface potentials <10V [13], although estimates of this effect still require significant refinement.

Conclusions: From a comparison with [7] it appears that sub-micron dust grains could contaminate astronomical observations of infra-red, visible and UV light over a significant portion of the lunar surface, and not just at the terminator. This one of many ways in which dust could interfere with science and exploration activities on the Moon [8], therefore a thorough understanding of lunar dust behavior is necessary in order to effectively tackle future problems.

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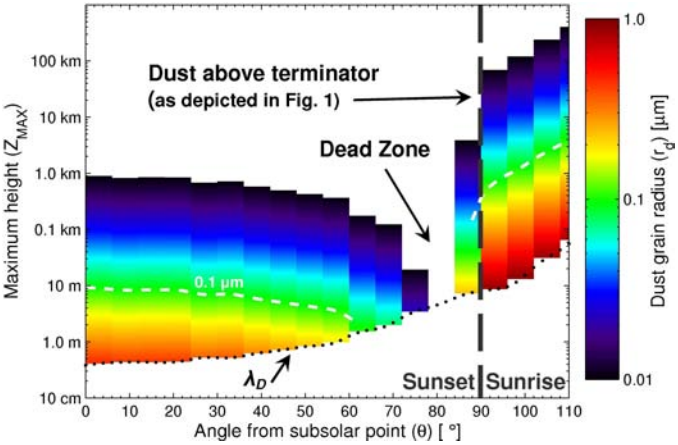

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