A DYNAMIC FOUNTAIN MODEL FOR LUNAR DUST. T. J. Stubbs, R. R. Vondrak and W. M. Farrell, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA, tstubbs@lepvax.gsfc.nasa.gov.

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] (e.g., Fig. 1). This was observed from the dark side of the Moon during sunset and sunrise by both surface landers and astronauts in orbit. These observations were quite unexpected, as the Moon was thought to be a pristine environment with 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]. It has since been demonstrated that this dust population could have serious implications for astronomical observations from the lunar surface [7].

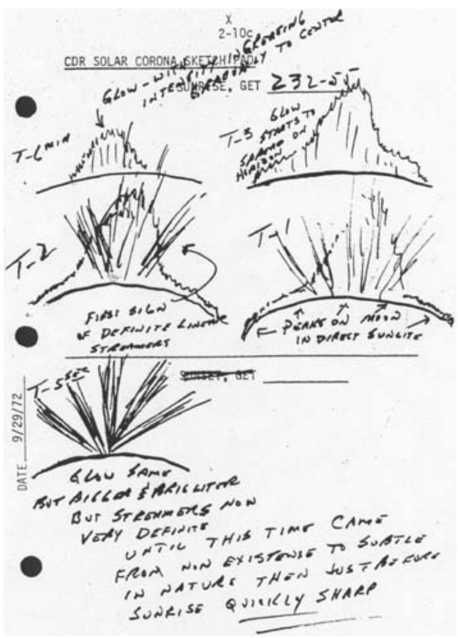


Fig. 1. Sketches of sunrise with "horizon glow" and "streamers" viewed from lunar orbit [1].

The lunar surface is electrostatically charged by the Moon's large-scale interaction with the local plasma environment and the photoemission of electrons due to solar ultra-violet (UV) light and X-rays [8]. The like-charged surface and dust grains then act to repel each other, such that under certain conditions the dust grains are lifted above the surface [2,3,4].

We present a dynamic "fountain" model (Fig. 2b) which can explain how sub-micron dust is able to reach altitudes of up to ~100 km above the lunar surface. Previous static dust levitation models are most applicable to the heavier micron-sized grains in close proximity to the surface, but they cannot explain the presence of extremely light grains at high altitudes. If we relax the static constraint applied to previous models, and instead assume that the grains are in constant motion (under the action of dynamic forces), a new picture emerges for the behavior of sub-micron lunar dust.

Apollo-era Observations: [3] argued that HG observed by the Surveyor-7 lander was caused by electrostatically levitated dust grains with radii, $r_d \approx 5$ µm, reaching heights of ~3–30 cm above surface irregularities in the terminator region (Fig. 2a). HG observations were ~10^7 times too bright to be explained by secondary ejecta from micro-meteoroid impacts [2,3].

Astronaut sketches of spacecraft sunrise showed HG and streamers above the lunar surface (Fig. 1), which varied on ~1–100s timescales indicating that they were produced by light scattering in the lunar vicinity by particles that were present sporadically [4]. Comparisons with a light scattering model indicated that HG had a scale height of ~10 km and was therefore unlikely to be caused by gases in the lunar exosphere, which have much greater scale heights [6]. Also, the vapour brightnesses of gases are below the threshold of visibility to the unaided human eye.

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.

The excess brightness in photographs of the solar corona taken from orbit above the lunar terminator were analyzed and could not be accounted for by a co-orbiting cloud of spacecraft contaminants [1]. Instead, it was concluded that it must be due to a variable lunar "atmosphere" of ~0.1 µm dust extending to altitudes in excess of 100 km, which was 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 our dynamic fountain model. 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, it is accelerated upward through a sheath region with a height of order the plasma Debye length, λ_D. 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

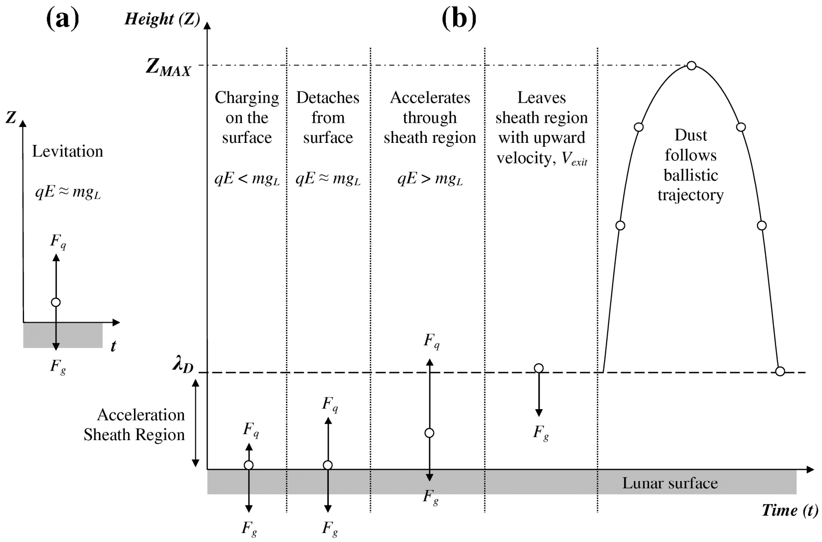


Fig.2. (left) Schematic comparing (a) the static levitation concept with (b) the evolution of a dust grain in our dynamic fountain model.

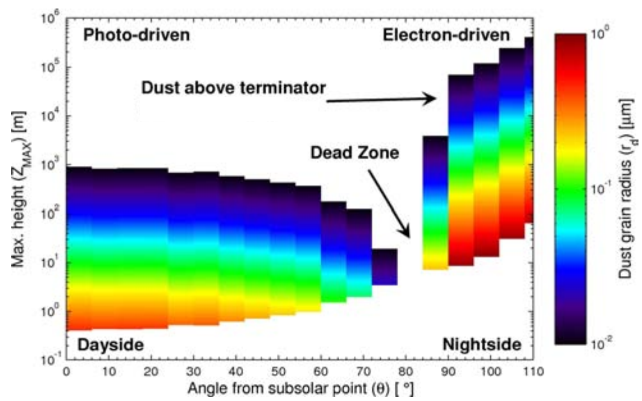
Fig. 3. (below) Spectrogram plot showing the maximum dust grain height reached (Z_{MAX}) as a function of angle from the subsolar point (θ) and dust grain radius (r_d).

follow a near-parabolic trajectory back toward the lunar surface since the main force acting on them now is gravity.

Model Results: Surface charging in the model is driven by photoelectron currents on the dayside and plasma electron currents 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. This reveals that dust can be lofted by the fountain effect at most locations on the lunar surface. However, there is an absence of lofted dust in a region just sunward of the terminator ($\theta \approx 80°$), which we refer to here as the "Dead Zone". In our model this marks the transition from surface potentials, $\phi_S > 0$ on the dayside to $\phi_S < 0$ on the nightside, where there is no net charging of the surface as $\phi_S \approx 0$. So no lofting of dust grains can occur there. Fig. 3 also shows that at the terminator dust grains <0.1 μm can be lofted to ~1–100 km.

Discussion and Conclusions: In the model presented here we have neglected the effects of: (1) grain adhesion to the surface [9], (2) secondary electron currents [8,10,11], (3) horizontal electric fields at the terminator [12], (4) the lunar wake on surface charging near the terminator [13,14], (5) collective behaviour on dust grain charging [11]. Of these, we would expect secondary electron currents and grain adhesion to have the most significant impacts.

From a comparison with [7] it appears that submicron 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, therefore a thorough understanding of lunar dust behaviour is necessary in order to effectively tackle future problems.



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