The Implications of Lunar Water on Electrostatic Dust Levitation

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The presence of water on the moon has recently been confirmed by observations from the M^3 instrument on Chandrayaan-1, the Cassini spacecraft and the Deep Impact spacecraft. The presence of water in colder terminator regions of the moon can lower the cohesive forces between regolith particles and lead to the preferential levitation of particles from the terminators.

Motivation:

Lunar horizon glow, a brightness above the limb of the moon at sunset, is thought to be caused by light scattering off of 10 micron dust particles above the lunar surface [1]. Micrometeoroid bombardment was ruled out as the source of the levitated particles due to an inadequate flux of impacts [2]. Dust particles are thought to be levitated off the lunar surface due to electrostatic forces. The Lunar Ejecta and Meteorites experiment from Apollo 17 qualitatively measured the reimpact of levitated dust particles, which were found to be most frequent during sunrise and sunset [3]. However, considerable uncertainty exists regarding the method through which dust particles collect sufficient charge to levitate.

Electrostatic Forces:

Previous work on the charging of particles on the surface of asteroids and the moon have considered the electron and ion currents from the solar wind and the photoemission current [4, 5]. By requiring the acceleration due to electromagnetic forces to be larger than gravity, we define the charge that a particle must have to levitate (Eqn (1), where a_{grav} is the local gravity, m_d is the mass of the particle and E_0 is the surface electric field strength).

$$Q_{req} \geq \frac{a_{grav} m_d}{E_0} \qquad (1)$$

Equating the electron and photoemission currents on the surface determines the amount of charge available. Given the available charge, the dust size, and assuming the charge is uniformly distributed over a finite area, the amount of charge accumulated on a single dust particle is $Q_{pre} = 4 r_d^2 E_0 \epsilon_0$ (where r_d is the radius of the particle and ϵ_0 is the electric constant).

Evaluating these results shows that the predicted charge is several orders of magnitude less than the charge required for levitation to occur. Criswell and De overcame this impediment by hypothesizing an enhanced electric field and charge concentration in the terminator region due to the close proximity of lit and shadowed areas [6], and the progression of sunset [7]. Increased surface electric fields have also been hypothesized when the moon is inside the Earth's magnetotail [5]. Additionally, other charging methods, such as secondary electron emission and triboelectric charging, could result in locally elevated surface charging.

Cohesive Complications:

The calculation of the charge required for levitation in Eqn (1) only considers gravity. If cohesive forces are included, the amount of charge required for levitation will increase further. Perko [8] estimates the cohesion on a 10 micron particle to be orders of magnitude larger than gravity, especially on the sunlit side of the moon. Any levitation theory must account for the increased resistance to levitation supplied by cohesion. Regions of lowered cohesion will thus be sites of preferential dust levitation.

Implications of Detected Water on Lunar Surface:

The M^3, Cassini and Deep Impact missions have recently confirmed the presence of water and hydroxyl on the lunar surface through the analysis of hyperspectral data [9, 10, 11]. The water is believed to be at or near the lunar surface, since it was detected in areas that had not been previously identified by the Lunar Prospector neutron spectrometer. The water concentration shows a correlation with surface temperature, with strengthened water signatures in colder regions. Pieters [9] and Sunshine [11] present a strengthened water spectral signature in the terminator (sunrise/sunset) region, which would be expected since the terminator is relatively cool. Clark argues that the increased absorption in the terminator region is an artifact due to the solar incidence angles [10]. Clark [10] estimates that there could be 10-1000 ppm by mass of water in the lunar regolith, although the specific water concentrations for different regions (for instance, the polar region as opposed to the subsolar point) are not described.

Perko [8] shows that the surface cleanliness strongly effects the strength of cohesive forces. Cleanliness is a nondimensional quantity varying from 0 to 1 that is approximately equal to the inverse of the number of layers of absorbate molecules surrounding a mineral particle [8]. As temperature increases and pressure decreases, the cleanliness of regolith increases, resulting in an increase in the cohesive forces acting on it. Perko states "water is the most readily absorbed gas and causes the lowest surface cleanliness"[8]. Thus, an increased presence of water in the terminator region will result in a lower surface cleanliness and thus weakened cohesive force as compared to regions of higher temperature. Assuming that water molecules occupy a spherical volume defined by the length of their hydrogen bond (2.75 Å), it is possible to calculate the number of water molecules required to completely enclose a single regolith particle of a given radius. We determine an effective thickness of the water shell. Figure 1 shows the cleanliness of the soil for a variety of particle sizes and water concentrations. From [8], we can see that the interparticle force is approximately proportional to the cleanliness squared. Thus, if we halve the cleanliness of a particle, the cohesion will be a quarter of the initial value. Perko [8] gives a simple method to calculate the added cohesion that will be felt by particles with a given water shell thickness in the lunar environment as compared to the terrestrial environment. The added cohesion can be from 1-10s of kPa, which is significant since the cohesion of lunar soil in the terrestrial environment is on the order of 1 kPa [8].

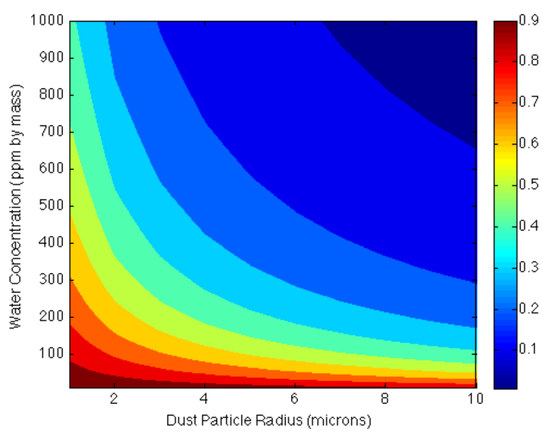

Figure 1: Cleanliness of soils with various particle sizes and water concentrations. Note cohesion decreases with cleanliness squared.

Since the strength of the cohesive force increases as temperature increases, the cohesive force is expected to be weakest at sunrise, where the surface temperature will be lowest. Thus, particles are expected to be preferentially levitated from the terminators, with increased activity at the colder sunrise terminator. The LEAM data [5] directly supports this hypothesis, showing peaks in impact activity at the terminator and a nearly 5-fold increase in levitation activity at sunrise as compared to sunset. However, if levitation were due solely to the Criswell and De supercharging, we would expect more levitation activity at sunset than sunrise, since supercharging relies on the contraction of the sunlit surface. Our analysis of the variation in cohesion over the lunar surface indicates preferential levitation of particles at the sunrise terminator, however, the method through which particles attain the required charge to levitate remains unknown.

Further Implications:

The source of the proposed lunar water is not yet fully substantiated. Pieters and Sunshine [9, 11] suggest that the detected water is likely to be produced through interactions of solar wind hydrogen ions with oxygen-containing minerals on the lunar surface [12], since a hydration and dehydration cycle is seen within the duration of a lunar day. If solar wind is confirmed as the lunar hydrogen source, then a similar presence of water can be hypothesized to occur on asteroids. If the spin of the asteroid is slow enough to result in temperature cycling, we could also see preferential levitation of particles in asteroid terminator regions.

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