A Preliminary Study on the Effect of Lunar-Dust Movement on the Lunar Magnetic Field.

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Introduction: It is known that the present Moon has no global magnetic dipole field. Data from former lunar exploration programs show that the lunar magnetic field is very weak, usually just a few nT. Variations in field strength are noted in different lunar areas, *e.g.*: the average magnetic field in young basins and craters is between 0.5-1.5 nT, with exceptions that antipodal of Nectaris, Serenitatis, and Crisium field strength is greater than 11 nT and antipodal of Imbrian and Orientale field strength exceeds 34 nT. In contrast, the average magnetic field over the entire lunar surface is only ~4 nT while the average field outside the five antipodal regions is only 3 nT. The antipodal grooved and pitted terrains are the most strongly magnetic widespread lunar regions with average magnetic fields > 67 nT [1].

The origin of the lunar magnetic field is still a controversial topic. There are two principal ways to obtain information regarding the origin of the lunar magnetic field: one is from lunar samples collected during the former lunar-landing programs, and the second is from magnetic measurement data from lunar missions (such as Magnetometer and Electronic Reflector on the Lunar Prospector Orbiter). Charged lunar dust floats on the lunar surface [2] and the movement of charged particles should be able to generate an induced magnetic field. To the best of our knowledge, however, there is no study on how the movement of charged lunar dust could have impacted the lunar magnetic field.

The purpose of the study is to design a model called “The Electromagnetic Induction Model of Charged Active Lunar Dust” based on the “Fountain Model” [3] and data from LEAM (Lunar Ejecta and Meteorites). The preliminary result shows that the contribution of the movement of charged lunar-dust to the lunar magnetic field is not negligible.

The motion characteristics of lunar dust: Owing to the low-gravity and near vacuum of the lunar surface, tiny lunar soil particles from lunar regolith are liable to float off the lunar surface once they become disturbed by human or natural activities. These floating particles are lunar dust. The size (r_d) of lunar dust is so small that particles are usually invisible to human eyes. These tiny particles have large specific surface areas and relatively good insulating properties so they can easily become charged under the low conductivity, high temperature and strong radiation conditions of the lunar surface. The interaction with solar wind is the main mechanism for the charging process of lunar dust: the lunar dayside charges positive as photoelectron currents caused by solar UV and X-rays dominate while the lunar nightside charges negative since plasma electron currents dominate [4]. The charged lunar dust can be levitated and transported due to the electrostatic charging of lunar surface and dust grains, which cause the dust to be repelled from the like-charged surface. The most obvious phenomenon of flying dust is the “Horizontal Glow” observed by astronauts and spacecrafts. Besides, it is also possible for the global-scale transportation of lunar dust from positive to negative surface potential to occur at the dayside of the terminator, that is to say, lunar dust can transport horizontally by potential difference across the lunar surface [2].

Stubbs, *et al.* [3, 4] designed the “Fountain Model” to study the motion characteristics of charged lunar dust. They analyzed the force condition and motion characteristics of lunar dust based on the lunar surface environment. In this model the charged dust grains follow ballistic trajectories subsequent to being accelerated upwards through a narrow sheath region from the lunar surface to the height of the Debye wavelength (λ_D) by a surface electric field. The fountain model demonstrates that lunar dust can be levitated from the lunar surface by a surface electric field and that particles with diameters of 0.01*u*m can fly to an altitude of 100 km [3].

The motion direction of lunar dust in the “Fountain Model” is mainly vertical. However, as we have mentioned before, horizontal electric fields exist at the lunar surface, especially at terminator areas where lunar surface potential changes from $\Phi_S > 0$ at the dayside to $\Phi_S < 0$ at the night side. So the charged lunar dust can be driven horizontally by the potential difference across the lunar surface. This has been directly detected by LEAM on Apollo17: the motion direction of lunar dust is mainly horizontal with the energy of the active particles ranging from 1×10^{-7} J to 1000×10^{-7} J while particle velocity ranges from 1 to 75km/s [5].

Considering the contradictions between the “fountain model” and data recorded by LEAM, we agree that the fountain model can explain the levitation mechanism of lunar dust and the phenomenon of lunar dust existing at 100 km altitude, but it cannot explain the horizontal movement of lunar dust which LEAM has detected. Combining the "fountain model" and data detected by LEAM, we consider that the main direction of lunar dust movement is horizontal and the levitation mechanism can be explained by the "Fountain Model". So we can now formally ask the question: Is there a relationship between the movement of charged lunar dust and the lunar surface magnetic field?

The electromagnetic induction model of charged active lunar dust: To answer the question above, we designed the "Electromagnetic Induction Model of Charged Active Lunar Dust" (Fig.1). To begin, we make some idealized assumptions to conceptualize the model. (1) Lunar dust consists of spherical particles evenly distributed in the lunar regolith layer. (2) Parameters used in our model are values in terminator areas; we ignored the vertical and rotational drift movement of lunar dust. (3) The velocity (V_l) used in our model is what the LEAM detected, the value of which ranges from 1km/s to 75km/s. We specify V_l = 75km/s for all the particles at terminator areas (as the potential difference there is the greatest), the direction of V_l is from the dayside to nightside. We take the magnitude of the induced magnetic field into account and ignore the direction. (4) During horizontal movement there is no interaction force between lunar dust particles. (5) The height from the lunar surface of our model is restricted to the Debye wavelength (λ_D) in terminator areas, and we take no account of the movement of lunar dust above this height. (6) Particles arranged closely from lunar surface to λ_D according to the descending order. (7) The lunar surface is flat.

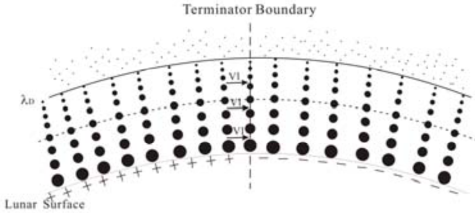

Fig.1: The Electromagnetic Induction Model of Charged Active Lunar Dust.

As is shown in Fig.1, lunar dust arranged densely at any given altitude and the intensity of the horizontal current (I_0) caused by the movement of charged lunar dust is:

$$I_0=\frac{Q}{t}=\frac{nq}{t}=\frac{V_l q}{2r_d}=\frac{V_l C\Phi_s}{2r_d}$$

, where r_d is the radius of lunar dust, C is the grain capacitance, Φ_S is the surface potential.

If we assume that lunar dust particles are spheres and $r_d \ll \lambda_D$, then we have: $C \approx 4\pi\varepsilon_0 r_d$

As the lunar surface is assumed to be flat, the movement of charged lunar dust at the same altitude can be regarded as an infinitely long current-carrying wire. According to the law of Biot-Savart, the strength of the induced magnetic field at a point on lunar surface is: $B_0=\frac{\mu_0 I_0}{2\pi h_v}$

Calculating the induced magnetic field (B) generated by all the active particles from the lunar surface (actually from r_{MAX}) to the height of λ_D we get:

$$B=\int_{r_{MAX}}^{\lambda_D}\frac{\mu_0 I_0}{2\pi h_v}d(h_v)=\int_{r_{MAX}}^{\lambda_D}\frac{\mu_0\varepsilon_0\Phi_s V_l}{h_v}d(h_v)$$

According to the "Fountain Model", we know that in the terminator area Φ_S=-36V and, after calculation, we get B=0.483nT.

Discussion: We know that the sensitivity of Electronic Reflector on LP is 0.2nT [1] and our result B is greater than that. By comparing B with the magnitude of the lunar magnetic field described in section 1, we can say that the movement of charged lunar dust has a great effect on the lunar magnetic field. However, as the model is based on an extremely idealized circumstance which is only suitable for terminator areas, we can neither say that the present model suits the whole lunar surface, nor that the movement of charged lunar dust is the origin of a lunar magnetic field.

At a minimum, we are convinced that the value we present here should receive consideration in that it suggests the movement of lunar dust has influenced the lunar magnetic field and the influence is not negligible; we have to consider the effect of the movement of lunar dust when we are dealing with the origin of the lunar magnetic field.

The model proposed here is preliminary and more work needs to be done. If we can settle the assumptions in section 3 more appropriately, this model could be applicable in areas other than just in terminator areas, and we should combine the characteristics of lunar soil and rocks when evaluating the contribution of the movement of charged lunar dust to the magnetic field of the lunar lithosphere.

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