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Gravitomagnetic Separation of Bipolar Charged Martian Dust

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The possible role of magnetic anomalies on Mars in gravitational enhancement of separation of charged dust is considered. It is known that charges become spatially separated by differential transport and gravitational sedimentation because the charge polarity of particles of dust depends on the particle size—where smaller particles are negatively charged and larger particles are positively charged; thus, smaller and predominantly negative charged particles populate higher regions of dust devils, and larger, positively charged particles fall to the ground. This study shows that gravitational separation could be enhanced by the presence of magnetic anomalies on Mars owing to the generation of a type of magnetobarrier that prevents gravitational settling of charged dust particles beyond a certain size threshold.

Keywords. *Dust storms, Electrostatic fields on Mars , Magnetic anomalies on Mars, Supersaturation atmosphere of Mars*

I. INTRODUCTION

It is known that large electric fields can be generated by atmospheric dust activity [1]-[4]; however, the mechanism by which negatively and positively charged particles become spatially separated to create the electrical field is not clear. It is believed that, because the charge polarity of dust particles depends on the particle size—where smaller particles are negatively charged, and larger particles are positively charged—charges become spatially separated because differential transport and gravitational sedimentation sort dust devil aerosols by size. Thus, smaller and predominantly negatively charged particles populate the higher portion of a disturbance, whereas larger, positively charged particles fall to the ground [5]-[9]. This particle size dependence of the charge polarity of dust has also been experimentally demonstrated [10].

The object of this work was to analyse the possible enhancement of gravitational spatial separation of bipolar charged dust owing to the presence of magnetic anomalies on Mars.

II. GRAVITOMAGNETIC SEPARATION OF CHARGED PARTICLES

The question examined in this letter is schematically illustrated in Fig. 1. Briefly, we want to determine whether local magnetic anomalies on Mars could create a type of *magnetobarrier* that acts as a particle size cutoff, thus enhancing gravitational separation.

First, for an imposed magnetic field to affect charged dust particles, its magnetic energy density must be comparable to the kinetic energy density of the charged particles; that is, the dynamic ram pressure from the dust particles must be equal to the magnetic pressure originating from the local magnetic field of Mars in that region. Because the low pressure of the Martian troposphere results in high electrical conductivity [11], the magnetic pressure p_m is given by

$$p_m = \frac{B^2}{\mu_o} \tag{1}$$

On the other hand, the dynamical pressure on particles resulting from gravitational settling is given by

$$p_g = \left(\frac{\rho_d u_t^2}{2}\right)_d \tag{2}$$

and therefore our condition $p_g \leq p_m$ yields

$$\left(\frac{\rho_d u_t^2}{2}\right)_d \leq \left(\frac{B^2}{\mu_o}\right) \tag{3}$$

where ρ_d is the charged dust density, u_t is the gravitational terminal velocity of dust particles, B is the magnetic strength in the region, and μ_o is the vacuum permeability.

The terminal velocity of the particles is approximately given by

$$u_t^2 = \frac{8\rho_p r_p g}{3\rho_\infty C_d} \tag{4}$$

where ρ_p is the density of the particles; r_p is the equal-volume sphere radius, i.e., the radius of a sphere having the same volume as the particles; ρ_∞ is the

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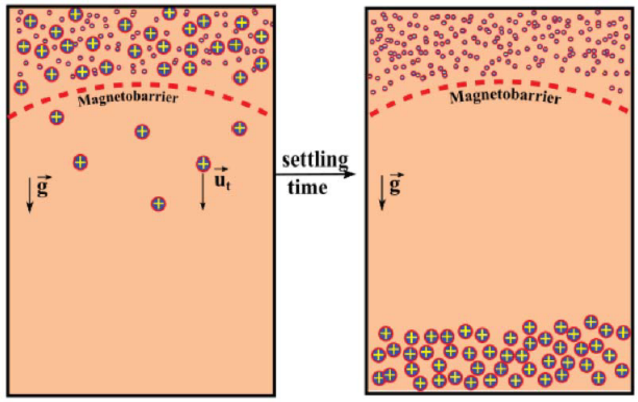

FIG. 1: Magnetobarrier induced by local magnetic field anomalies acting on charged dust particles on Mars could generate an effective spatial separation mechanism by creating local electrostatic fields.

atmospheric density through which the particles are falling; C_d is the drag coefficient, which is a function of the particle Reynolds number and the shape of the particles given by the sphericity, ψ (see the appendix); and g is the acceleration due to gravity. The weighted mean radius of the particles depends on the assumed size distribution; sizes of 0.4 μm [12]) and[13], 2.5 μm [14], and 10 μm [15]) have been reported. Thus, there is significant uncertainty regarding the actual size of the particles, and it is best to assume that the particles are between 0.1 μm and 10 μm in size.

The gravitational field varies with distance as $\frac{1}{a^2}$, where a is the radial distance to the centre of the planet. Thus, Eq.(4) becomes

$$u_t^2 = \frac{8\rho_p r_p g_o a_o^2}{3\rho_\infty C_d a^2} \tag{5}$$

where g_o is the gravitational acceleration at the surface, and a_o is the radius of the planet. Finally, the density of the dust is given by

$$\rho_d \approx \frac{4\pi r_p^3 \rho_p N_p}{3} \tag{6}$$

where N_p is the concentration of dust particles per unit volume. This concentration is a first approximation given as a function of the optical opacity as [16]

$$N_p = N_o \tau \exp^{-\frac{z}{H}} \tag{7}$$

where $N_o = 6 \times 10^6$ m^{-3} is the number density at the surface when the optical depth $\tau = 1$, and $H = 10$ km is the scale height. Substituting terms, Eq.(3) becomes

$$B > \frac{4\rho_p a_o r_p^2}{3a} \left[\frac{\pi N_o \tau \exp^{-\frac{z}{H}} g_o \mu_o}{\rho_\infty C_d} \right]^{\frac{1}{2}} \tag{8}$$

We assume reasonable values of the parameters: $\rho_p \approx 3 \times 10^3$ kg m^{-3} [16]; dust is suspended at a tropospheric distance of 10 km, so $\frac{a_o}{a} \approx 0.98$; $N_o = 6 \times 10^6$ m^{-3}; $z = 10$ m, and the scale height $H = 10$ km [16]; $g_o = 3.7$ m s^{-2}; $\rho_\infty = 10^{-2}$ kg m^{-3}; and $\psi = 1.0$, so $C_d \sim 0.5$ (see the appendix). Then we obtain

$$B > 314 \times \tau^{\frac{1}{2}} r_p^2 \tag{9}$$

where B is in nT, and r_p is in μm.

- **Discussion**

The resulting curves are shown in Fig. 2. The hypothesised magnetobarrier induced by the typical regions of anomalies on Mars could enhance the gravitational separation for typical particle sizes (from 0.1 μm to 10 μm). Finally, in our previous estimation, we assumed that all of the suspended dust is charged. If polarisation occurs in only a fraction of the cloud, f_c, then Eq.(9) can be rewritten as

$$B > 314 \times f_c^{\frac{1}{2}} \tau^{\frac{1}{2}} r_p^2 \tag{10}$$

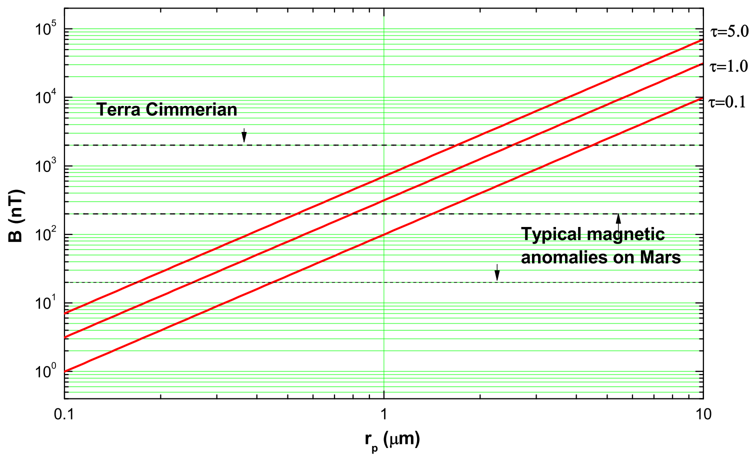

FIG. 2: Curves predicted by Eq.(9) for various dust storm parameters.

The resulting curves are shown in Fig. 3, considering as an example a dust cloud with optical opacity $\tau = 1$ and charged fractions of the suspended dust of $f_c = 1.0$, $f_c = 0.1$, and $f_c = 0.01$.

III. FORMATION OF SUPERSATURATED CAVITIES

Within the framework of the present theory, magnetic anomalies could enhance the gravitational separation, producing *gravitomagnetic separation*; however, in addition, because the magnetobarrier acts as a particle size cutoff, it can be speculated that for highly charged clouds, as the settling time increases, a region devoid of dust will be generated. This situation is sketched in Fig. 4, which shows the separation of charges after 5 h of gravitational settling for a cloud with $\tau = 1.0$. This region cannot result from pure gravitational separation because in this case there would be no particle size cutoff, and all of the particles will fall, although with different velocities; thus, there would be a continuous region of dust particles. Until recently, it was generally assumed that these supersaturated regions cannot exist in the cold Martian atmosphere; however, their existence was recently confirmed by SPICAM data, which showed extremely high levels of supersaturation, up to 10 times greater than those on Earth. Further research is required to evaluate this hypothesis.

IV. SUMMARY OF RESULTS AND CONCLUSIONS

Enhanced gravitational separation of charged dust due to the presence of magnetic anomalies on Mars was discussed. It was shown that coupling of the magnetic and gravitational fields could result in the formation of a type of magnetobarrier that acts as a particle size cutoff or threshold that prevents gravitational settling of smaller particles. Because this magnetobarrier could result in considerable separation of charged dust, it makes the formation of local electric fields more likely. Furthermore, for highly charged dust clouds, this gravitomagnetic separation could lead to the formation of regions devoid of dust (condensation nuclei on Mars), and thus to supersaturated regions.

V. APPENDIX

A. Nonspherical Particles

Our previous discussion assumed spherical particles, and thus a representative value of the drag coefficient of around $C_d = 0.5$. However, the most general situation involves nonspherical particles. The drag coefficient of nonspherical particles is usually calculated by describing the shape of the particles in terms of their sphericity, ψ, which is defined as the ratio of the surface area of a sphere having the same volume as the given particle to the surface area of the particle [17]. Typical sphericity values range from $\psi = 0.125$ (platelets) to 1.0 (spheres).

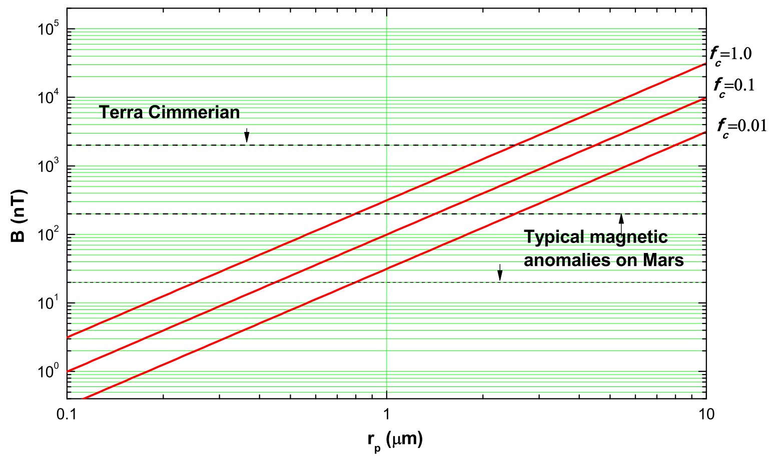

FIG. 3: Curves predicted by Eq.(10) for several polarisation fractions and a dust storm with optical depth $\tau = 1.0$.

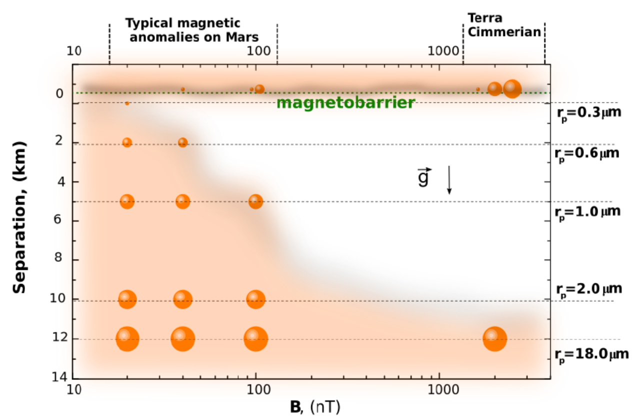

FIG. 4: Cavity formation. If the magnetic strength is high enough, separation of charges by gravitational settling can result in regions totally devoid of dust (condensation nuclei on Mars) and thus in supersaturated regions.

Fig. 5 shows the effect of the sphericity on the drag coefficient C_d versus the Reynolds number of the particles [18], where the particle Reynolds number for nonspherical particles, $\mathbf{Re}_p$, is based on the equal-volume sphere diameter, i.e., the diameter of a sphere having the same volume as the particle.

According to Eq.(8), our estimation scales by $C_d^{-\frac{1}{2}}$, or a factor of approximately 0.125, if highly flattened particles are assumed instead of spheres. To illustrate this result, Fig. 6 is the same as Fig. 2 for $\tau = 1.0$ except

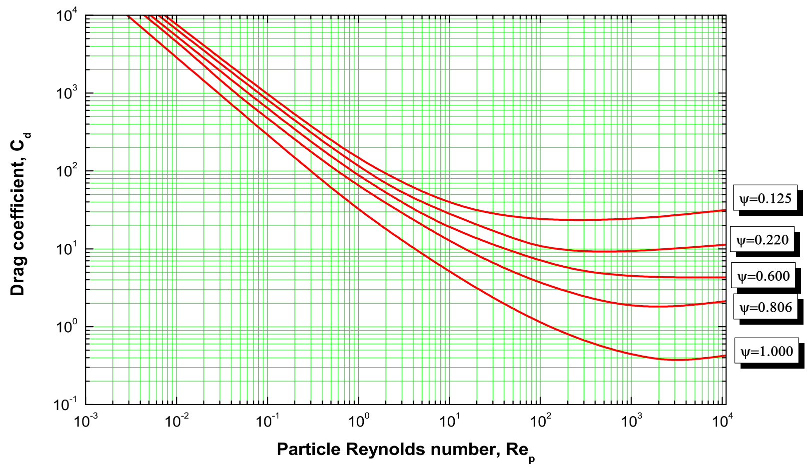

FIG. 5: Drag coefficient C_d versus Reynolds number $\mathbf{Re}$ for particles of sphericity ψ ranging from 0.125 (platelets) to 1.0 (spheres).

that $C_d = 0.5$ and $Cd = 32$ are assumed for spherical and flattened particles, respectively.

NOMENCLATURE

a_o = radius of the planet
a = radial distance of the dust cloud
B = magnetic field
C_d = drag coefficient
f_c fraction of dust electrically charged
g = gravity
g_o = surface gravity
H = height scale
N_o = number density at surface
N_p = concentration particles per unit volume
p_g = dynamical (ram jet) pressure of particles
p_m = magnetic pressure
r_p = radius of particle
$\mathbf{Re}_p$ = particle Reynolds number
u_t = terminal velocity
z = height

Greek symbols

μ_o = magnetic permeability
ρ_p = density of particle
ψ = sphericity factor of particle
ρ_d = density of dust
ρ_∞ = density of atmosphere
τ = optical opacity

Subscripts symbols

m = magnetic
g = gravitational
t = terminal
d = draw/ dust
p = particle
o = surface value

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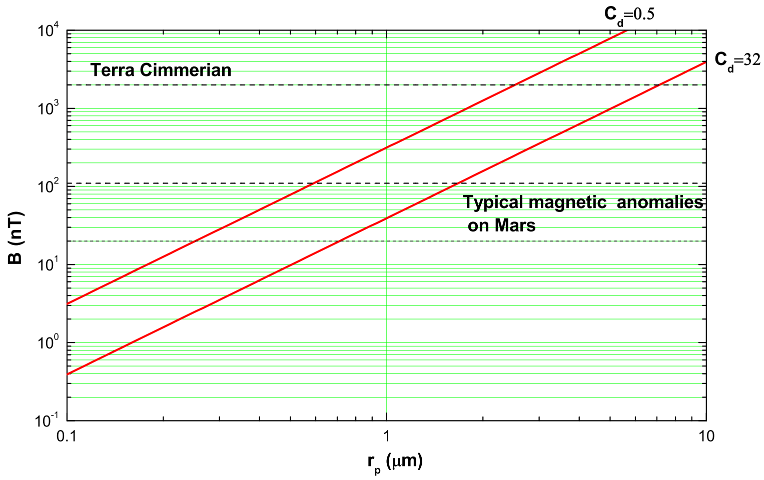

FIG. 6: Curves predicted by Eq.(9) for $\tau = 1.0$ assuming $C_d = 0.5$ and $C_d = 32$ for spherical and flattened particles, respectively.

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