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Dusty plasma effects in Earth's magnetospheric plasma perturbed by a cosmic body

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Abstract

Dusty plasma effects related to cosmic bodies which can appear in the vicinity of the Earth are studied. We consider two possibilities for appearance of the dust, namely (1) cosmic bodies entering the Earth's magnetosphere are embedded in a dust cloud and (2) dust grains appear as a result of condensation after destruction of a cosmic body due to an explosion which pursues the goals to prevent "asteroid hazard", and take into account the process of dust particles charging in the magnetosphere. We show that the presence of charged dust particles can result in formation of a current system in the magnetosphere and study its possible consequences for the Earth's environment.

Cosmic body embedded in a dust cloud

Let us consider a cosmic body embedded in a dust cloud (like the comet Shoemaker-Levy 9) and moving through the magnetosphere of the Earth with a speed $\mathbf{U}$ relative to the corotating magnetospheric plasma. Interaction of the magnetospheric plasma with particles of the dust cloud results in charging of the latter. The equilibrium charge of a dust particle is established in the process of equalization of electron and ion currents on this particle, and (for thermal equilibrium distributions) it can be determined from the equation $\omega_{pe}^2 \exp(-z)/v_{Te} = \omega_{pi}^2 (t+z)/v_{Ti}$, where $t \equiv T_i/T_e$, $z \equiv Z_d e^2/aT_e$, $\omega_{pe(i)}$ is the electron (ion) plasma frequency, $v_{Te(i)}$ is the electron (ion) thermal velocity, $T_{e(i)}$ is the electron (ion) temperature, $-e$ is the electron charge, a is the size of the dust particle, $-e$ is the electron charge, $-Z_d e$ is the dust particle equilibrium charge. Here, we carry out all estimates for the parameters of the plasma layer of the magnetosphere: $T_i = 5 \cdot 10^2$ – $5 \cdot 10^3$ eV, $T_e = 2 \cdot 10^2$ – $2 \cdot 10^3$ eV, $B = (1-2) \cdot 10^{-4}$ Gs, $n_i = 1$ cm^{-3}; the ion composition is H^+, He^{++}, O^+, He^+, N^+. For $t = 2.5$ we have $z = 2.59$. For the parameters of the plasma layer we obtain $Z_d \approx 3.64 \cdot 10^5 a$, where a is expressed in units of μm. The characteristic frequency of the dust charging process is

$$\nu_q = \frac{\omega_{pi}^2 a}{\sqrt{2\pi} v_{Ti}} (t+z+1) \,. \qquad (1)$$

For the above parameters we obtain $\nu_q \approx 1.90 \cdot 10^{-5} a$, where a is expressed in units of μm while ν_q in units of s^{-1}. Thus, during the time of about L/U (where L is the characteristic size of the plasma layer) the dust grain can acquire the charge determined by the charge number

$$\tilde{Z} \sim Z_d \min\{\nu_q L/U, 1\} \,. \qquad (2)$$

Furthermore, in space (e.g., in planetary rings, etc.) the distribution of dust particles in sizes can be represented as [1]

$$n_d(a) \approx 2 n_d a_0^2 / a^3, \quad n_d = \int_{a_0}^{a_1} n_d(a) da, \qquad (3)$$

where n_d is the density of dust grains, $a_{0(1)}$ is the minimum (maximum) size of the dust particles, $a_0 \ll a_1$. For the typical value of the comet velocity $U \approx 20$ km/s, the size L of about $10 R_E$, where R_E is the Earth's radius, and assuming that the speeds of the dust particles coincide with the velocity of the comet, one can easily see that not all of the dust grains acquire the equilibrium charge characterized by Z_d. For the particles with $a \ll 20$ μm (the minimum size a_0 does not exceed 1 μm usually [1]) the charge number $\tilde{Z}$ is less than Z_d.

The presence of the cloud consisted of charged dust particles in the Earth's magnetosphere can result in a possibility of formation of a global current system. Effect of its formation is due to the differential motion between the negatively charged dust particles and the corotating (with the Earth) plasma. The dust grain moves across the magnetic field whereas the magnetospheric thermal ions must gyrate along the magnetic field lines and hence are trapped in corotation with the Earth with velocity V_r. The relative motion of these two charge carriers in the azimuthal direction will lead to a current with the density

$$j \approx -\left\langle n_d \tilde{Z} \right\rangle e (U - V_r), \qquad (4)$$

where the angular brackets denote averaging over the distribution $n_d(a)$: $\left\langle n_d \tilde{Z} \right\rangle = \int_{a_0}^{a_1} n_d(a) \tilde{Z} da$. The dust current flowing across the magnetic field lines will be mapped from the dust cloud to the Earth's ionosphere

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via a system of field–aligned currents. The situation is analogous to that predicted by [2] for the case of interaction of the comet Shoemaker–Levy 9 with the Jovian magnetosphere and ionosphere.

Let us evaluate the current $I \sim \pi r^2 j$ for the total number of dust grains in a dust cloud ($N \approx 3 \cdot 10^{20}$) and the radius of the dust cloud ($r \sim 10^4$ km), which are close to those related to the comet Shoemaker–Levy 9 [2], for the space body velocity of 20 km/s, and for the distribution (3) over the dust grain sizes with $a_0 = 1$ μm (in [2] it was assumed that the dust grains all have a single radius distribution of $a = 1$ μm). For the distances between the cosmic body and the Earth surface less than 10 Earth's radii we find $V_r < 4$ km/s and $I \sim 10^4$ A. Thus sufficiently intensive current appears. The width of the current flow can be comparable to the size of the dust cloud [2]. In this case the electrodynamical coupling of currents flowing in different directions is possible. Electrodynamical coupling of intense currents normally trigger characteristic auroral processes, including parallel electric fields, energetic particle acceleration along field lines and precipitation, together with the generation of radio waves. These processes would lead to the detection of enhanced level of auroral UV and radio emission.

Destructed cosmic body

Let us consider the effects in the magnetosphere which can be caused by a micrometeoroid shower appearing after the destruction of a cosmic body by an explosion (for the prevention of "asteroid hazard"). After the explosion the matter of the cosmic body evaporates. The evaporated gas forms a cloud with the energy E and the mass M, which expands inertially with the mean velocity $U = \sqrt{2\varepsilon_0}$. Here, $\varepsilon_0 \equiv E/M$ is the initial internal energy which is supposed to be larger significantly than the vaporization heat. Initially the gas cooling in the process of its expansion is adiabatic. At the time t_1 after the beginning of the gas expansion the saturation of the gas occurs and the process of the condensation starts. All centers of condensation appear at the beginning of the process of condensation during very short period. Later the condensation occurs only by means of attachment of vapor moleculas to the centers of condensation. The condensation stops soon after the gas density in the process of expansion becomes so low that the rate of the attachment (which is proportional to the gas density) cannot maintain the equilibrium between the attachment of the moleculas to the drops (condensation centers) and the vaporization of the drops. The final size of the drops a can be determined from the scaling

$$a \propto M^{1/3} \varepsilon_0^{-1/2} n_1(\varepsilon_0)^{2/3}, \qquad (5)$$

where n_1 is the gas density in the state of saturation. The drops propagate in the plasma layer of the magnetosphere like the dust grains from the previous example. The drops acquire the charges determined by the charge number (2), and the global current system is formed.

For an iron body with the mass $M = 4 \cdot 10^{10}$ g and the magnitudes of ε_0 less than 100 eV/atom the charging of the drops occurs and the magnitudes of the current are very high. If the radius of the current system coil is about $3R_E$ then the magnetic field created by this current is $B \sim 5 \cdot 10^{-3}$ Gs (in the case of $\varepsilon_0 = 25.6$ eV/atom when $I = 8 \cdot 10^6$ A) and $B \sim 5$ Gs (in the case of $\varepsilon_0 = 71.9$ eV/atom when $I = 10^{10}$ A). Thus the structure of the magnetosphere can be violated significantly for sufficiently large meteorite with the mass of the order of 10^{10} g.

Such a violation of the magnetosphere structure can be prevented if one uses so powerful explosion that the drops have very high speed and, therefore, do not have enough time to acquire the charge. The condition for this is determined from the inequality $\nu_q Z_d L/U < 1$. Using the scaling (5) and the latter inequality we find the condition which enables one to express the magnitudes of ε_0 (when the effect of charging of the drops is avoided) in terms of the mass M

$$\left(\frac{M}{\bar{M}}\right)^{\frac{2}{3}} \left(\frac{\bar{\varepsilon}_0}{\varepsilon_0}\right)^{\frac{3}{2}} \left(\frac{n_1(\varepsilon_0)}{n_1(\bar{\varepsilon}_0)}\right)^{\frac{4}{3}} < 4 \cdot 10^{-4}, \qquad (6)$$

where $\bar{M} = 4 \cdot 10^{10}$ g and $\bar{\varepsilon}_0 = 71.9$ eV/atom.

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References

[1] Tsytovich, V.N. (1997) *Phys. Usp.*, 40, 53–94.

[2] Ip, W.-H. and Prangé, R. (1994), *Geophys. Res. Lett.*, 21, 1051–1054.