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Goddard Space Flight Center
Contract No. NAS-5-9299

ST - IM - PF - 10467

CHARGED DUST PARTICLES IN INTERPLANETARY SPACE

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31 MARCH 1966

ST - IM - PF — 10 467

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Astronomicheskiy Zhurnal
Tom 43, No. 1, 192 - 7,
Izdatel'stvo "NAUKA", 1966

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SUMMARY

Inferences following from the assumption that dust particles of interplanetary space are electrically charged, are discussed. It is shown that in this case a natural explanation befits a series of observed regularities in the zodiacal light, the gegenschein, the twilight glow and in noctilucent clouds. The possibility is shown of circumterrestrial dust cloud replenishment by submicron dust, always "blown away" by the solar wind from the lunar environment. The submicron particles are trapped by the geomagnetic field, forming the most stable component of the circumterrestrial dust cloud.

* * *

If the dust particles of interplanetary space carry along an electrical charge, they must be subject to the action of magnetic fields. In the free interplanetary space they will be acted upon by the magnetic field of the solar wind, and besides, near the Earth they will be subject to the action of the Earth's magnetic field.

The electric potential of a dust particle is conditioned by its interaction with electrons and ions of interplanetary space and by the photoeffect induced by the action of Sun's ultraviolet and X-ray radiation. The question of body potential in interplanetary space was reviewed in the works [1 — 8]. The possible values of potentials, found in these works, oscillate from several tens of volt to several kilovolts. Without pausing at the consideration of these works, we shall point out that it is impossible, at present, to derive a reliable conclusion on the magnitude of the potential of a dust particle on the basis of theoretical considerations only, for the

* O ZARYAZHENNYKH PYLEVYKH CHASTITSAKH MEZHPLANETNOGO PROSTRANSTVA.

necessary data on physical properties of the surface of dust particles and on density distribution of particle energy of the interplanetary plasma are absent. Despite this, the possibility cannot be excluded that, under specific conditions, the potential of dust particles may have a sufficiently great value.

We shall demonstrate below that the assumption of dust particles being electric charge carriers provides the possibility to explain some of the observed regularities.

Assuming the interplanetary dust particles being charged allows us to explain the gegenschein, or counterglow, by these particles' accumulation in the region of the Earth's magnetohydrodynamic tail, considered theoretically by Piddington [9] and detected with the aid of AES Imp I, or Explorer-18 [10]. There exists in the Earth's magnetic tail a neutral zone, dividing the field regions of opposite orientation, in which tiny dust particles may accumulate. Piddington assumed [9] that gas particles, trapped in the neutral zone of the tail, may explain the counterglow. However, the concept of Earth's gas tail is less acceptable than that of the dust tail. First of all, the facts, on the basis of which the assumption was made of the existence of Earth's gas tail, have at present dropped off. We have in mind the Karimov's result [11] about the enhancement of night sky emission lines in counterglow, which was refuted by the works of Pariyskiy and Gindilis [12], Weinberg [13], and others. Measurements of hydrogen emission intensity in the line H_α serve as a serious argument against the concept of Earth's gas tail. As was shown by Fishkova [14] and Shcheglov [15] measurements, an intensity minimum of hydrogen glow is observed in the counterglow region, although according to Shcheglov data [15], the intensity distribution of hydrogen emission in the zodiacal light region corresponds to intensity distribution in the visible region of the continuous spectrum. As in the case of zodiacal light, the explanation of couterglow by light scattering in gases is met with the requirement of having high gas concentrations on account of the small effective scattering cross section of gas particles by comparison with dust particles. Thus, there is no basis to assume that the counterglow is explained by the Earth's gas tail and, consequently, the concept of dust tail is more acceptable than the former.

In the case, whereby the Earth's magnetic tail serves as a reservoir for dust particle accumulation, these particles must also accumulate in the magnetohydrodynamic tail of the Moon, recently discovered with the aid of the Imp I satellite [16]. This allows a natural explanation for the recently revealed dependences of zodiacal light brightness and its axis' position on the age of the Moon [17, 18]. The influence of the Moon on the near-the-Earth dust cloud is difficult to explain by the gravitational action only. This influence is naturally explained if one assumes that in the Moon's magnetic tail, which according to Ness [16] spreads at least over 150 lunar radii, there exists an accumulation of dust particles, of which the concentration is higher than in the remaining sublunar space.

In this case there is also a natural explanation for the dependence of the twilight sky brightness on the age of the Moon, revealed in [19 - 21]. As was pointed out in [21], the distribution of dust at heights of ~200 km above ground, where the events considered still observed, is not linked with the density distribution of Earth atmosphere gases. This is why the dependence of twilight sky brightness (and consequently of dust concentration in the upper atmosphere) on the age of the Moon can not be explained by lunar tides in the terrestrial atmosphere. It may be connected with the influence of Moon's dust tail. Note that the dust particles of Moon's tail may also contribute substantially to the F-corona.

The existence of the magnetohydrodynamic tail of the Moon assumes that the Moon has a magnetic field, which, according to Vestine [22] and Neugebauer [23], may be pressed by the solar wind to the lunar surface, or even compressed under the surface. In this case the solar wind will "blow away" the dust particles rising over it at meteorite impacts or for other causes. Inasmuch as the particles of lunar surface may also have an electric potential [6, 7], they must be carried by the magnetic field of the solar wind, moving helicoidally along the lines of force. Thus, the Moon may be a source of dust, moving from the Moon into interplanetary space under the action of the magnetic field of the solar wind.

We shall now examine which particles may be subject to the effective action of magnetic fields. According to Parker [24], particles of radius

$a = 10^{-4}$ cm with a 10 v potential will be subject to considerable perturbation from the side of the solar wind's magnetic field. For particles with $a < 1.2 \cdot 10^{-5}$ cm the gravitational attraction of the Sun will be less than the Lorentz force.

Let us consider at further length the correlations of gravitational, light pressure and Lorentz forces acting upon a particle of the near-Earth dust cloud.

For the Lorentz force we have

$$F = \frac{q}{c}\bar{v} \times \bar{B}, \qquad (1)$$

where v is the particle velocity of the relative field (in case of the Sun's magnetic field this is the velocity of particles relative to solar wind); q is the charge of the particle; c is the speed of light ; B is the magnetic induction, which in the given case is the equivalent intensity (see [25]). Expressing the charge through the potential U and the radius a of the particle, assumed to be spherical ($q = aU/300$), we obtain

$$\bar{F} = \frac{aU}{300c}\bar{v} \times \bar{B}. \qquad (2)$$

Here the potential is expressed in volts and B in gauss. Assuming that the potential of the particle is, for instance, 10 v, we shall obtain for the module of the Lorentz force L_0 of solar wind's magnetic field (at the distance of 1 a.u. from the Sun)

$$L_{\odot} = 1.3 \cdot 10^{-10}\, aU = 1.3 \cdot 10^{-9}\, a \text{ dynes}; \qquad (3)$$

if we assume that $B = 3 \cdot 10^{-5}$ gauss and $v = 4 \cdot 10^{7}$ cm.sec^{-1} (solar wind velocity). Analogously, for the Lorentz force of the geomagnetic field at the distance Δ from the center of the Earth we shall obtain the value of its module $L_{♁}$ (the particle velocity is perpendicular to the direction of the field):

$$L_{♁} = \frac{aUv}{300c\Delta^3}B_{♁} = 3.4 \cdot 10^{-8}\, aU = 3.4 \cdot 10^{-7}\, a \text{ dynes} \qquad (4)$$

Here we assumed for the velocity of particles $v = 10^{6}$ cm $\cdot$ sec^{-1} and for the magnetic moment of the Earth the value of $8.1 \cdot 10^{25}$ gauss $\cdot$ cm^3, which gives $B_{♁} = 0.31$ gauss (Δ is expressed in Earth's radii).

For the force of the gravitational attraction of the Sun $F_\odot$ at the distance of 1 a.u. , for the gravitational attraction of the Earth $F_♁$ at the distance of Δ terrestrial radii from the Earth's center and for the gravitational attraction of the Moon at its surface $F_☾$, we have

$$F_\odot = \frac{GM_\odot}{r^2}\cdot\frac{4}{3}\pi\rho a^3 = 2.5\rho a^3 \text{ dynes} \quad (5)$$

$$F_♁ = \frac{GM_♁}{\Delta^2}\cdot\frac{4}{3}\pi\rho a^3 = 4.1\cdot 10^3\frac{\rho a^3}{\Delta^2} \text{ dynes} \quad (6)$$

$$F_☾ = \frac{GM_☾}{r_☾^2}\cdot\frac{4}{3}\pi\rho a^3 = 6.9\cdot 10^2\rho a^3 \text{ dynes} \quad (7)$$

Here ρ is the density of the dust particle in g cm^{-3}; Δ in Earth's radii, a in cm. The Sun's light pressure force upon a particle of a cm radius, situated at the distance of 1 a.u. from the Sun, is expressed by the dependence

$$R_\odot = \frac{\pi a^2 Q_{press} I}{c} = 1.5\cdot 10^{-4} Q_{press}\, a^2 \text{ dynes} \quad (8)$$

where the intensity of solar radiation at the distance of 1 a.u. is $I = 1.4\cdot 10^6$ erg $cm^{-2}\cdot sec^{-1}$. The value of the efficiency factor of light pressure Q_{pres} for totally reflecting particles may be borrowed from the work [26].

TABLE 1

Force	$\Delta(r_♁)$	$a=10^{-6}$ cm	$a=10^{-5}$ cm	$a=10^{-4}$ cm	$a=10^{-3}$ cm
$L_♁$	1	$3.1\cdot10^{-13}$	$3.1\cdot10^{-12}$	$3.1\cdot10^{-11}$	$3.1\cdot10^{-10}$
	5	$2.5\cdot10^{-15}$	$2.5\cdot10^{-14}$	$2.5\cdot10^{-13}$	$2.5\cdot10^{-12}$
	10	$3.1\cdot10^{-16}$	$3.1\cdot10^{-15}$	$3.1\cdot10^{-14}$	$3.1\cdot10^{-13}$
	50	$2.5\cdot10^{-18}$	$2.5\cdot10^{-17}$	$2.5\cdot10^{-16}$	$2.5\cdot10^{-15}$
	100	$3.1\cdot10^{-19}$	$3.1\cdot10^{-17}$	$3.1\cdot10^{-17}$	$3.1\cdot10^{-16}$
$L_\odot$	1 a.e.	$1.2\cdot10^{-15}$	$1.2\cdot10^{-14}$	$1.2\cdot10^{-13}$	$1.2\cdot10^{-12}$
$R_\odot$	1 a.e.	$7.5\cdot10^{-20}$	$3.8\cdot10^{-14}$	$1.6\cdot10^{-12}$	$1.5\cdot10^{-1}$
$F_♁$	1	$4.1\cdot10^{-16}$	$4.1\cdot10^{-13}$	$4.1\cdot10^{-10}$	$4.1\cdot10^{-7}$
	5	$1.6\cdot10^{-17}$	$1.6\cdot10^{-14}$	$1.6\cdot10^{-11}$	$1.6\cdot10^{-8}$
	10	$4.1\cdot10^{-18}$	$4.1\cdot10^{-15}$	$4.1\cdot10^{-12}$	$4.1\cdot10^{-9}$
	50	$1.6\cdot10^{-19}$	$1.6\cdot10^{-16}$	$1.6\cdot10^{-13}$	$1.6\cdot10^{-10}$
	100	$4.1\cdot10^{-20}$	$4.1\cdot10^{-17}$	$4.1\cdot10^{-14}$	$4.1\cdot10^{-11}$
$F_\odot$	1 a.e.	$2.5\cdot10^{-19}$	$2.5\cdot10^{-16}$	$2.5\cdot10^{-13}$	$2.5\cdot10^{-10}$
$F_☾$	surface of the Moon	$6.9\cdot10^{-17}$	$6.9\cdot10^{-14}$	$6.9\cdot10^{-11}$	$6.9\cdot10^{-8}$

Compared in Table 1 are the modules of the forces $L_♁$, $L_\odot$, $R_\odot$, $F_♁$, $F_\odot$ and $F_☾$, computed for particles of various dimensions, situated at various distances Δ from the center of the Earth. The table is compiled for hollow little spheres with mean density $\rho = 0.1\ g \cdot cm^{-3}$, charged to the 10 v potential. The light pressure force R_0 is computed for dielectric particles with an index of refraction $m = \infty$.

As may be seen from Table 1, the Lorentz force of the geomagnetic field near the ground is much greater than the Lorentz force of the solar wind's field. For distances $\Delta = 5\ R_E$ these forces are comparable and at further driving off the Earth the magnetic field of the solar wind becomes prevailing. For particles with radii $a = 10^{-6}$cm the Lorentz forces of the two considered fields are substantially greater than the Sun's light pressure force and the gravitational attractions of the Earth and of the Sun. For particles of $a = 10^{-5}$ cm size the Lorentz force of the solar wind has the order of Sun's light pressure force. Near the Earth these forces are less than the Earth's gravitational attraction, but they become equal to it already at a distance of about $5R_E$ from the center of the Earth. At distances $< 5\ R_E$ the Lorentz force of the geomagnetic field exceeds the Earth's gravitational force. Thus, for particles with $a = 10^{-5}$ cm, the electromagnetic forces have a significant value at all distances from Earth.

The role of the magnetic field may also be estimated by way of computation of the magnetic hardness

$$R = \frac{mvc}{q} = \frac{4}{3}\frac{\pi\rho a^3 vc}{aU}\cdot 90\,000 = 1.13\cdot 10^{16}\frac{\rho a^2 v}{U}\ \text{v}.$$

For the geomagnetic effects of a moving particle to exist, its magnetic hardness must be less than the threshold magnetic hardness, which is $6 \cdot 10^{10}$ v at the terrestrial surface. Assuming as earlier that

$$v = 10^6 \text{cm} \cdot \text{sec}^{-1}, \quad \rho = 0.1\ \text{g cm}^{-3} \text{ and } U = 10\ \text{v},$$

we obtain $a < 2 \cdot 10^{-5}$, which corresponds to the conclusion derived on the basis of data of Table 1.

Thus, submicron particles with radii of $10^{-6} - 10^{-5}$ cm must be subject to significant Lorentz forces, exceeding the light pressure force. The magnetic fields of the solar wind and of the Earth will determine the character of motion of these particles in interplanetary space. The calculations performed confirm the possibility of existence of dust tails of the Earth and of the Moon, consisting of submicron particles charged to 10 v potential and having the average density of about $0.1\ g \cdot cm^{-3}$.

Submicron particles of size $5 \cdot 10^{-6} - 5 \cdot 10^{-5}$ cm were collected in noctilucent clouds with the help of rockets [27, 28] and also in the 88 - 168 km altitude range with the aid of the "Venus flytrap" rocket [29]. Analysis of twilight observations allowed us to conclude [30] that at height of the order of 100 km above the Earth's surface there exists a tiny submicron dust, whose concentration decreases with height substantially faster than the concentration of coarser particles detected with the help of pickups on satellites. This may be explained by the fact that the Earth's magnetic field, trapping the charged submicron particles, prevents their fall on the Earth's surface. Similarly to particles conditioning the aurorae, the submicron charged dust particles will penetrate into the Earth's atmosphere substantially easier at high geomagnetic latitudes than in the equatorial region. This would also explain the latitude dependence of the frequency of noctilucent cloud appearance, possibility pointed at by Witt [31]. Note that submicron particles were precisely the ones detected in noctilucent clouds; their size was $5 \cdot 10^{-6} -$ $5 \cdot 10^{-5}$ cm, which increases substantially the tangibleness of the assumption made by us. Attention should also drawn in connection with the above to the recently revealed dependence of the rate of dust accretion on the geomagnetic latitude [32]. pointing to an increase in the rate of dust accumulation with the rise of geomagnetic latitude. It is true though, that this dependence was obtained for coarse particles of the size $10^{-4} - 10^{-2}$ cm, for which the magnetic hardness was found to be above threshold. In the case whereby the dependence revealed in [32] of the accretion rate on geomagnetic latitude is real, there arises the problem of theoretical explanation of the possibility of high potential's presence in particles with $a > 10^{-4}$ cm. On the other hand, this dependence provides the possibility to assume that submicron particles too may have high potentials.

Aside from the above-indicated regularities we should draw attention on the correlation, revealed by Blackwell and Ingham [33], between the brightness of zodiacal light and the perturbation of the magnetic field after a solar flare, and also on the brightness increase of counterglow in the period between two polar aurorae revealed by Pariyskiy and Gindilis [12].

The consideration, brought up here, show that the assumption of the fact that the dust particles of the near-Earth cloud carry along an electrical charge, is quite probable, inasmuch as it provides the possibility of explaining a series of observed regularities and allows to interpret the presence of submicron particles in the near-Earth dust cloud as a result of their capture by the geomagnetic field.

***** THE END *****

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Manuscript received on 11 May 1965

Contract No.NAS-5-9299
Consultants & Designers, Inc.
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Translated by ANDRE L. BRICHANT on 30 March 1966

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