# LORENTZ SCATTERING OF INTERPLANETARY DUST GRAINS

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ABSTRACT. The scattering of dust grains orbits due to recurrent sectors of the interplanetary magnetic field is reinvestigated with a better formalism. Our method reveals the resonant character of the diffusion and is well suited for the problem. The spreads in the orbital parameters are found less important than believed untill now and to vary rapidly with eccentricity and semi-major axis. Only the small dielectric grains with size less than 0.5 μm may be scattered by the Lorentz force fluctuations; the main diffusion occurs in inclination and near the sun (20-60 $R_{\odot}$).

## 1. INTRODUCTION

The diffusion of charged dust grains by the fluctuations of the interplanetary magnetic field (IMF) is a mechanism often considered in the dynamics and the origin of the zodiacal cloud. The previous studies on this subject (Parker,1964; Consolmagno,1979; Morfill et al,1979) are either limited to simple cases or unsatisfactory. So, we have reexamined the problem with a formalism developped from the quasi-linear theory in Plasma Physics (Barge et al,1982a). The keplerian orbits of the dust grains are assumed weakly perturbed by the random Lorentz force and the diffusion time is taken much smaller than the Poynting-Robertson life-time in such a way that a statistical approach with a Fokker-Planck approximation can be used. As explained in a previous paper (Barge et al, 1982b) the diffusion of keplerian orbits only occurs if the spectrum of the fluctuations encloses modes which are resonant with the orbital frequency. Therefore only the low frequency fluctuations associated with the large scale structure of the IMF have to be considered. Moreover it is clearly better to take three constants of the unperturbed motion ($K_i$) with their associated cyclic variables as new dynamical variables since , for example, the Fokker-Planck equation then becomes a simple diffusion equation. A convenient choice of the invariant is: $K_1 = E/2\omega_0$ where E is the energy and $\omega_0$ the orbital frequency, $K_2 = h$ (the modulus of the angular momentum), $K_3 = h_z$ (the projection of $\vec{h}$ onto the spin axis).



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## 2. SCATTERING BY MAGNETIC SECTORS

At heliocentric latitudes less than 15° the polarity of the interplanetary magnetic field and the solar wind speed are observed to be function of time; moreover the magnetic polarity appears divided in N sectors of opposite sign (N=2 or 4). Due to the random evolution of the large scale structure of the IMF the size of the sectors is stochastic and the periodicity of the field reversals have a gaussian like probability distribution P (Sawyer, 1976). The high-speed streams of the solar wind are reccurent with the same statistics because of their correlation with the IMF structure; in connection with the wind fluctuations, the charge of the grains may also vary stochastically. In fact, the various contributions to the Lorentz force give a diffusion which have grossly the same order of magnitude; so, we shall examine only the case of the diffusion by magnetic polarity fluctuations.
The following description of the IMF has been adopted:

$$B_r(\vec{r},t) = \langle B_r \rangle f_N(\vec{r},t)$$
$$B_\theta(\vec{r},t) = B_1 \; r_0/r \; f_N(\vec{r},t)$$
$$B_\phi(\vec{r},t) = \langle B_\phi \rangle f_N(\vec{r},t)$$

where $\langle B_r \rangle$ and $\langle B_\phi \rangle$ are the two components of the mean magnetic field of Parker, $f_N$ is a function expressing the stochasticity of the magnetic polarity and $B_1$ is the magnetic perturbation associated with hydromagnetic fluctuations. The $B_\theta$ component has also been assumed to vary as 1/r (Consolmagno, 1979) and, from the power spectra of the IMF (Coleman, 1968), $B_1$ is deduced to be approximately $10^{-1}$ $(\sqrt{\varepsilon})$ smaller than the mean magnetic field $B_0$. We have also assumed $f_N$ to be a function generated by a structure made up of N straight sectors rotating with the sun.
Then, after a Fourier expansion of the function $f_N$ and of the orbital quantities (like the velocity), the diffusion coefficients $\langle \Delta K_i \Delta K_j \rangle / \Delta t$ can be derived from the motion equations (see Barge et al, 1982b, for detailled calculations). They are function of the power spectrum of $f_N$ which is also related to the probability distribution P. As an example, for circular orbits, we have:

$$\frac{\langle \Delta K_1{}^2 \rangle}{\Delta t} = (qwr_0B_0)^2 \pi\varepsilon \int d\omega \sum_{m,l} C_l^2 \frac{2}{N} \langle f_N^2 (\omega,m) \rangle \; \delta\left[\omega + (m+l)\omega_0\right]$$

where w is the wind velocity, $C_l$ is a Fourier coefficient, $r_0 = 1$ AU and $\delta$ is the Dirac distribution. See Barge et al (1982b) for the complete set of coefficients. Then, it is easy to derive the diffusion coefficients in the orbital parameters (semi-major axis a, eccentricity e, and inclination i) from the relations:

$$\dot{a} = -\frac{2}{\mu m} a^2 \omega_0 \dot{K}_1$$

$$\dot{e^2} = -\frac{2}{\mu m} a\omega_0 (1-e^2)^{1/2} \left[ (1-e^2)^{1/2} \dot{K}_1 + \dot{K}_2 \right]$$

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$$\dot{i} = \frac{1}{\mu m} \frac{a\omega_0}{\sin i\,(1-e^2)^{1/2}} \left[\cos i\, \dot{K}_2 - \dot{K}_3\right]$$

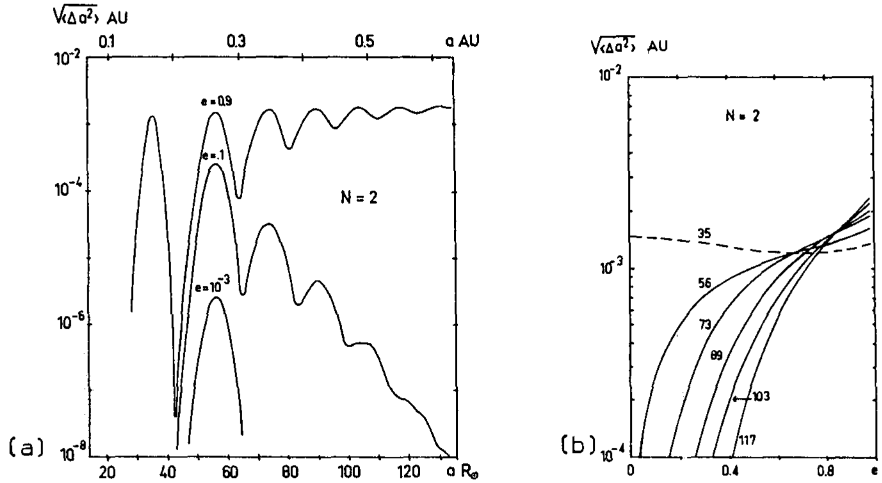
with $\mu = GM_\odot$.
The diffusion coefficients in a, $e^2$ and i have been numerically computed for a 2 sectors and a 4 sectors structure and for two values of the inclination. The square roots of the mean square changes of the orbital elements can be determined for a time interval of 10 years (approximately the duration of a solar cycle).
In the case of a 1 μm obsidian grain charged to a potential of 6 volts the spread in semi-major axis and in inclination are plotted as a function of the semi-major axis in figs 1a and 1b and as a function of the eccentricity in figs 2a and 2b, respectively.
(i)The most interesting feature on figs 1a and 1b is the wavy behaviour which is a direct consequence of the resonance between waves and orbital motions. The maxima of diffusion occur for orbits with semi-major axis satisfaying the relationship :

$$a = a_c\left(\frac{2n}{N}\right)^{2/3}$$

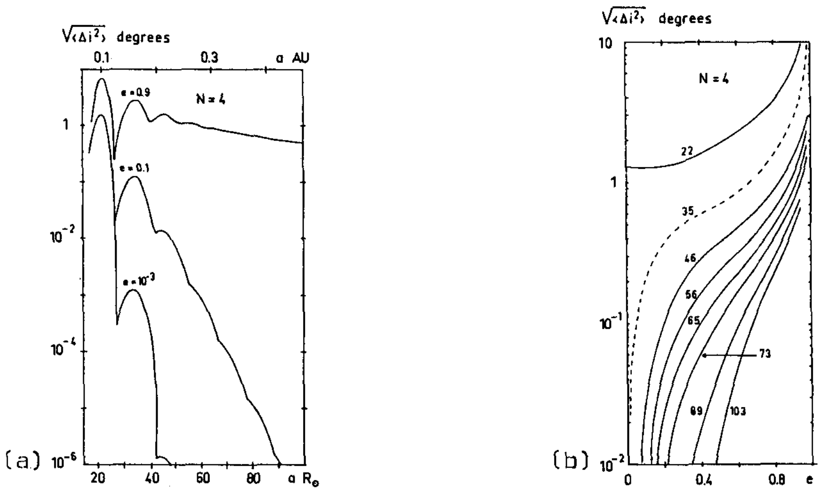
where $a_c$ = 0.165 AU is the distance of corotation with the sun. On the other hand the general trend of the changes in the orbital elements shows a decrease of the diffusion with increasing semi-major axis.
(ii) The magnitude of the changes in the orbital elements begin to increase with increasing eccentricities (this behaviour is due to the increasing number of orbital harmonics); then, for high eccentricities, the general trend prevails with a behaviour in $(1-e^2)^{1/2}$ for the dispersion in eccentricity and in $(1-e^2)^{-1/2}$ for the dispersion in inclination. Initial inclination plays a minor role.

## 3. DISCUSSION AND CONCLUSION

The Poynting-Robertson drag force is known to take the particles inward to the sun with a decay time $(\Delta t)_{P-R}$ depending on the eccentricity of the orbit. From the work of Wyatt et al(1950) it is easy to show that $(\Delta t)_{P-R}$ is greater than the diffusion time (ie) that the diffusion can take place:
(i) if the eccentricities are less than 0.8
(ii) if the eccentricities are greater than 0.8 and if a > 1 AU.
On the other hand the dispersions in the orbital elements depend on the physical characteristics of the grains (material, size, charge).
For example if we consider two materials (iron and obsidian), only the small obsidian grains with size less than 0.5 μm and confined in the vicinity of the sun (20- 60 $R_\odot$) may be diffused. The main diffusion occurs in inclination: for 0.2 μm grains the dispersion is of the order of a few ten degrees near the first resonance of a 4 sectors structure (23 $R_\odot$) and falls down to only a few degrees at the next resonance.
Finally, we conclude that in the vicinity of the solar equatorial plane the stochastic Lorentz force have a negligible effect on the dynamics of most zodiacal dust grains.




Figs. 1 Spread in semi-major axis (i = 0°): (a) versus semi-major axis, (b) versus eccentricity




Figs. 2 Spread in eccentricity (i = 0°): (a) versus semi-major axis, (b) versus eccentricity

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