INTERACTION OF THE COMETARY DUST WITH THE SOLAR WIND AND COMETARY PLASMA

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ABSTRACT. Along the lines of previous studies on the cometary dust-plasma interaction processes, we evaluate the electromagnetic effect of submicron dust in the coma and in the dust tail. The possible occurence of electrostatic disruption of charged dust in the ion tail is also discussed from theoretical and observational points of view. The relevance of these processes to the formation of striae in the dust tails of several comets is addressed and the conclusion is made that trajectory study of the submicron dust in the striae must take into account the action of the interplanetary electric field.

It has long been recognized that electrostatic charging effect of interplanetary dust of micron or submicron size could lead to strong perturbation of their orbital motions (Parker, 1964; Levy and Jokipii, 1976; Consolmagno, 1979; Morfill and Grün, 1979). As estimated by Mukai (1981), an equilibrium of photoelectron current and the currents of the solar wind electrons and ions to the surface of the dust particles produces surface electrostatic potential (Φ) on the order of +0.5 to +2.9 volts for graphite particles and +4.2 to +6.5 volts for silicate particles during average solar wind condition at 1 AU. Note that these are values pertinent to particles of radii > 1 μm, and for particles with smaller radii up to 0.03 μm the corresponding values of Φ will be larger due to their increasing absorption cross sections of solar radiation.

Since the electron charge on a dust grain with surface potential Φ is

$$Q = 2.4\mathrm{x}10^{-4}\ \Phi.r.e \qquad (1)$$

with Φ in V and the particle radius r in cm, the Lorentz force experienced by the charged dust particle can be written as

$$\begin{aligned} \underline{f}_L &= Q.(\underline{E} + \underline{V}_d \mathrm{x} \underline{B}_i) \\ &= 2.4\mathrm{x}10^{-4}\ \Phi.r.e\ (\underline{E} + \underline{V}_d \mathrm{x} \underline{B}_i) \qquad (2) \end{aligned}$$

where $\underline{V}_d$ is the dust velocity relative to the comet, $\underline{B}_i$ is the inter-

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planetary magnetic field, and $\underline{E} = -\underline{V}_{sw}\times\underline{B}_i$ is the interplanetary electric field acted on the charged dust particles. Because $V_d \leq 10$ km/s and $V_{sw} \approx 400$ km/s we have

$$\underline{f}_L = 2.4\times10^{-4}\ \Phi.r.e\ \underline{E} \tag{3}$$

and the corresponding acceleration is simply

$$\underline{a}_L = 5.7\times10^{-5}\ (e\Phi/r^2 d)\cdot(\underline{V}_{sw}\times\underline{B}_i), \tag{4}$$

where m_d is the mass of the dust particle and d its average density. For typical values of Φ ($\approx$ 5 V), V_{sw} ($\approx$ 400 km/s), B_i ($\approx 10^{-4}$ gauss), d ($\approx$ 1 g/cm^{-3}) we find $a_L \approx 0.06$ cm/s^2 for r $\approx$ 1 μm and $a_L \approx 5.5$ cm/s^2 for r $\approx$ 0.1 μm. In comparison, the solar gravitational acceleration at 1 AU is $a_g = 0.6$ cm/s^2. It thus can be seen that the motion of submicron dust particles with the ratio $a_L/a_g > 1$ are strongly influenced by their interaction with the interplanetary electric field.

The above consideration implies that the motions of submicron cometary dust, after their release from the cometary nuclei, could be affected significantly by the electrodynamic force of the solar wind plasma (Wallis and Ip, 1982; Wallis and Hassan, 1983). In the vicinity of the cometary comas, the motions of the dust particles relative to the cometary nuclei can be approximated as:

$$\dot{\underline{V}}_d = \underline{a}_p + \underline{a}_L, \tag{5}$$

where a_p is the radial acceleration due to the solar radiation pressure. Now assuming $\underline{a}_p \perp \hat{\underline{a}}_L$, it can be seen that - as was first pointed out by Wallis and Hassan (1983) - the trajectories of the charged dust particles will be deflected from the Sun-comet line by an angle θ given by $\tan\theta = a_L/a_p$.

Another effect of interest concerns the plasma drag effect of the cometary ions on the charged dust particles in the vicinity of the cometary ionosphere or ion tail. From a simple photochemical model, it has been found that the plasma density in the central axis of the ion tail cannot be larger than 10^3 cm^{-3} for a medium-bright comet like Comet Kohoutek 1973 XII at 1 AU solar distance. This small plasma density then limits the plasma drag effect to be quite negligible as first stated by Notni (1964, 1966). Even so, the ion tail could still have very strong coupling with the dust coma in case auroral-type activities could take place there as was postulated before (Ip and Mendis, 1976). Impact by an intense flux of energetic electrons could lead to electrostatic fragmentation of the cometary dust of fluffy structure (Hill and Mendis, 1980; see also Fechtig et al. 1979; Rhee, 1976; Öpik, 1956).

Note that Larson and Sekanina (1984) have found one event of narrow dust jet formation in the anti-sunward direction in the coma of Comet Halley - during its last perihelion passage. The association with electrostatic disruption of the dust particles is by no means clear; but it should be considered as one possible interpretation. The least could be said, in the present context, is that the interesting study by Larson and Sekanina has demonstrated the possibility of correlating the fine structures of cometary comas with energetic plasma processes in the ion tails.

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If the dust jet detected in Comet Halley's tail contained a large amount of submicron particles (or hypothetical dust jets created by electrostatic fragmentation in the ion tail) their subsequent motions would be determined by electromagnetic force as well as the solar radiation pressure. In order to present the simplest possible picture, we have considered the case in which the interplanetary electric field at 1 AU is the same throughout the whole ion tail and the solar wind; also the dust jet is supposed to have a linear structure with uniform distribution of particles of radii between 1 µm and 0.1 µm. The 0.1 µm particles are assumed to experience a solar radiation pressure acceleration of 1 cm/s^2 and a Lorentz force term of 0.6 cm/s^2 in the perpendicular direction; the 1 µm particles are assumed to have a_p of 0.5 cm-s^2 and a_L of 0.1 cm/s^2. The differences in the values of a_p and a_L would lead to the gradual separation of the particles of different sizes as shown in Fig. 1. Under steady state condition, the action of the interplanetary electric field is to spread a linear dust jet into a thin sheet of highly elongated configuration.

Without electrostatic charging effect, the dust particles would move purely according to their corresponding solar radiation pressure forces, and mechanical theory alone needs to be employed to interpret the brightness distribution (i.e., synchrons and syndyns) in the dust tails (Finson and Probstein, 1968a; Kimura and Liu, 1977). However, when the Lorentz force term is significant as appropriate to submicron particles, great care must be taken in using the mechanical theory to trace the trajectories of the dust particles. The implication on the study of the evolution of the striae in the dust tails of Comets West 1976 VI, Mrkos 1957 V and others as investigated by Sekanina and Farrell (1980, 1982) is clear as these banded structrues are composed mostly of submicron dust particles.

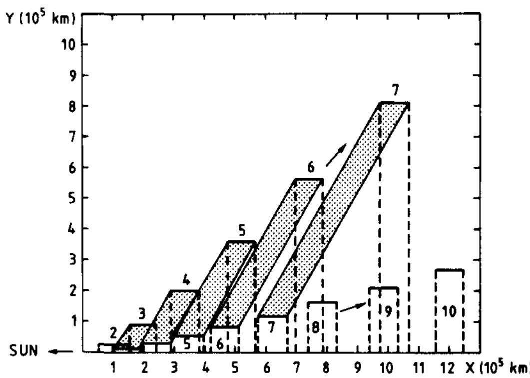

Fig. 1 An illustration of how a narrow jet of dust particles in the tail might evolve into a thin sheet with the particle sizes being arranged according to the values of a_L/a_p. The numbers denote the time intervals in days after the initial injection of the dust particles; and the bottom line represents the particle beam of 1 µm radius and the upper line represents the particle beam of 0.1 µm radius. All the dust particles share the same initial radial speed of 0.3 km/s. If f_L = 0, the dust jet will be elongated in the radial direction only

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In summary, in consideration of the dust-plasma interaction in the vicinity of cometary comas and ion tails, we have assessed the effects of:

a. Lorentz force of the interplanetary electric field (important);
b. plasma drag by the cometary ionospheric plasma (insignificant);
c. electrostatic disruption of cometary dust (possible);
d. electromagnetic perturbation of submicron particles in the dust tails (important).

Recent results of investigation of the fine-scaled structures of cometary comas using image enhancement method (Larson and Sekanina, 1984) have demonstrated the feasibility of monitoring the process of electrostatic fragmentation of dust particles in the comas and ion tails of comets. A simple calculation of the trajectories of submicron dust particles initially confined in a narrow jet in the anti-sunward direction allows us to estimate the long-term effect of the Lorentz force. On the basis of this study, it could be stated with some certainty that tracing of the motions of the striae in the dust tails of several comets must incorporate the pertinent electromagnetic effect due to interaction with the solar wind plasma.

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