CHARGED DUST RINGS IN THE OUTER PLANETARY MAGNETOSPHERES

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In this paper we discuss the motion of charged dust in outer planetary magnetospheres, particularly that of Jupiter. An increase of almost two orders of magnitude in the dust flux was observed as Pioneer 10 approached within about 30 R_J of Jupiter (Humes et al., 1975). Mendis (1978) suggested that this was a result of electrostatic disruption of interplanetary dust entering the Jovian magnetosphere and the subsequent magnetogravitational trapping of the disruption products. Subsequently, we (Hill and Mendis, 1979) have discussed in detail the physical and dynamical processes associated with the entry of interplanetary dust (assumed to be largely fragile aggregates of the Brownlee type) into the Jovian magnetosphere.

The charging of the grains, which is controlled mainly by electron and ion collection and photoemission (on the dayside) is shown in Figure 1. The equilibrium potentials are about -650 V on the dayside and -800 V on the nightside, the effect of the rapid relative motion between the dust and the plasma being included in the calculation.

Fragile grains disrupt on charging up to a critical potential which depends on their size and tensile strength. This situation is illustrated in Figure 2. Strong grains charge up to large potentials. On the other hand, a 20 μ dust ball entering the Jovian plasmasphere will get charged up to a potential of about -200 V in about 4 minutes, when it disrupts (point A). The eventual potentials attained by the different sized fragments are shown by C_1, C_2 and C_3, with the potentials of the smaller fragments being determined by the field emission limit.

Confining ourselves to the equatorial plane (see Hill and Mendis, 1979) we proceed to evaluate the orbits of these charged dust fragments in the Jovian magnetosphere, which is co-rotating up to about 35 R_J. The orbits of different sized fragments of parent grains entering the outer edge of the magnetodisc at two different angles are shown in Figure 3. The grain fragments are pulled toward Jupiter by the co-rotational electric field, the orbits being more strongly altered in the retrograde case.

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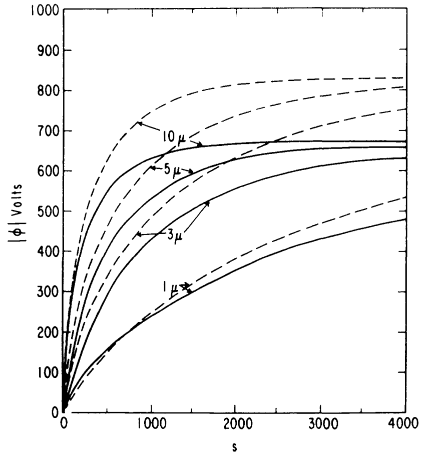

Figure 1. Charging rates of different sized grains in the Jovian magnetosphere. Solid lines correspond to the dayside while broken lines correspond to the nightside.

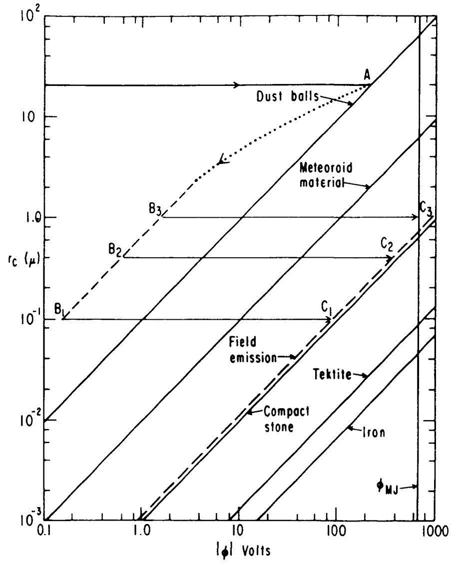

Figure 2. Critical grain radii for the electrostatic disruption of various materials; the stable regions being above the respective lines.

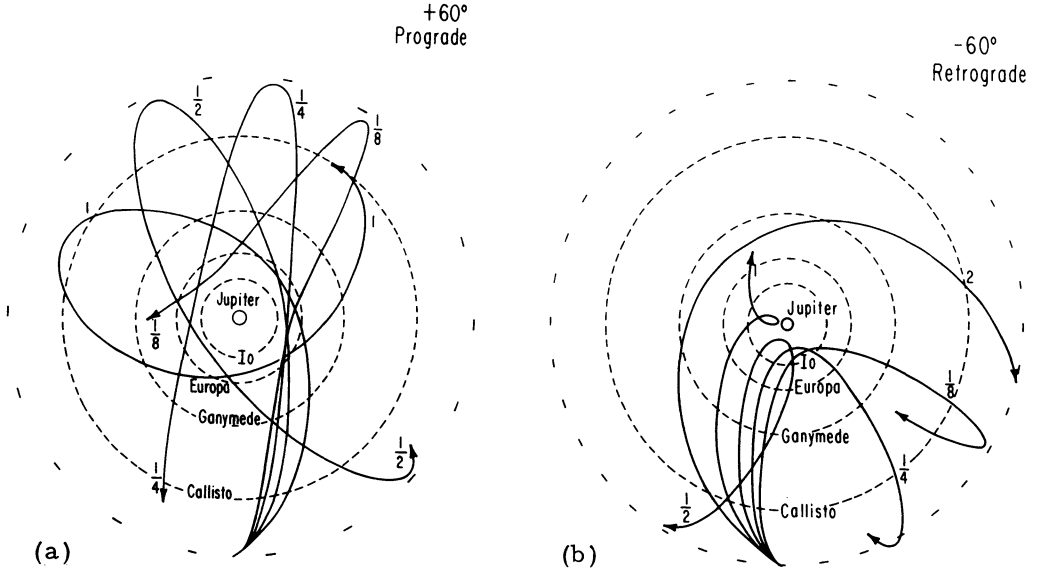

Figure 3. Orbits of fragments of a parent-grain which enters the Jovian magnetosphere at 35 R_J. (a) At an angle of 60° away from Jupiter in the prograde direction. (b) At an angle 60° away from Jupiter in the retrograde direction.

The distribution after one week of 1 μ-sized grain fragments entering the Jovian magnetosphere at 35 R_J pointed directly towards Jupiter (0^o) is shown in Figure 4a. The bimodal nature of the distribution is clearly a result of the longer times spent by the grains in the vicinity of their turning points. The distribution after a period of 8 weeks is shown in Figure 4b. Energy is being continuously sapped from the grains and their apicenters are gradually moving in as they get more tightly bound to Jupiter.

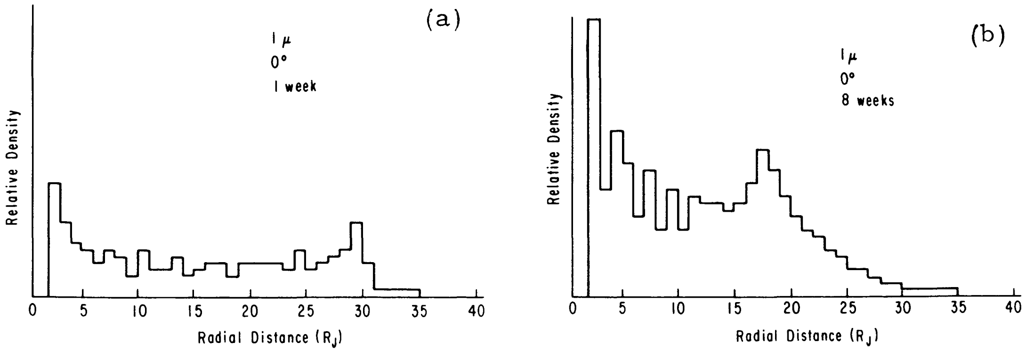

Figure 4. Spatial distribution of 1 μ grain fragments entering the Jovian magnetosphere at 35 R_J pointed directly towards Jupiter (0^o). (a) After one week. (b) After eight weeks.

Finally, Figure 5 shows the composite distribution after 200 hours for 1 μ fragments projected at 10 different, equally spaced angles from 35 R_J. While a few particles escape, the rest distribute themselves in the way shown, with two broad humps. With time, all the distribution modes will move inward and congregate around the minimum distance. Consequently, the eventual distribution of the grains, if they survive long enough, would be a fairly thin band, with each grain moving in a more or less circular orbit. It is tempting to suggest that the thin ring observed around 1.8 R_J by the Voyager spacecraft may be composed of these long-lived grains that eventually congregate towards the inner edge of the dust belt. We have also calculated the motion of the dust emitted from Io, since these may, alternatively, be suggested as the source of the observed dust ring. This dust does not penetrate to less than 4 R_J, and thus seems unlikely to produce the observed ring.

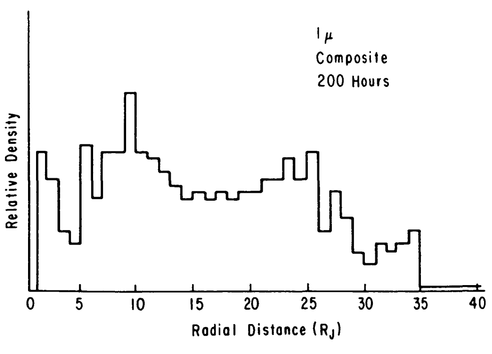

Figure 5. Composite distribution after 200 hrs of 1 μ fragments projected at 10 different equally spaced angles at 35 R_J.

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In conclusion, it is noteworthy that the directions of impact of these charged grains on the surfaces of the inner and outer satellites as seen in Figures 3, 4 and 5 are of such a nature as to produce the observed brightness asymmetries between their leading and trailing faces as suggested by Mendis and Axford (1974).

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DISCUSSION

Mukai: I think in the magnetosphere the sputtering of a grain due to high energy protons and charged particles trapped in the magnetic field becomes important. How did you treat the size decrease of a grain?
Hill: That ought to be a longer term effect. These calculations covered only two months. The grain size was kept constant after fragmentation in this model.

Singer: It is quite correct that Pioneer 10 does see an increased counting rate near Jupiter by a factor of 10 to 30. The Pioneer micrometeorite penetration detector is not sensitive to small particles ($<10^{-9}$ g). We believe that the Pioneer 10 observations near Jupiter can be accounted for purely by considering the gravitational "focusing" produced by the planet (cf. S. F. Singer and J. E. Stanley, Icarus 27, 197-205, 1976). Thus it may not be necessary to invoke nongravitational forces or mechanisms.
Hill: Yes. However, I don't see why gravitational focusing would produce a sudden increase in density around 30 R_J which I think was observed.
Cook: There are too few actual counts to tell one way or the other.
Hill (addendum): The laboratory calibration of Pioneer 10 detector suggests an "energy-like" detection threshold of the form $mv^{2.5}$ (see Singer and Stanley, 1976). Since our charged grains, strongly accelerated by the co-rotational electric field, are traveling with speeds of 6 to 7 times the typical Kepler speeds assumed in the purely gravitational calculation, the mass threshold of detectable grains is lowered by about two orders of magnitude to around 10^{-11} g. This corresponds to a threshold radius of only about 1 μ, if the bulk density is assumed to be around 2 gcm^{-3}.