HISTORY OF THE DUST RELEASED BY COMETS

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INTRODUCTION

The origin of the Zodiacal cloud has been attributed to an influx of cometary debris which maintains a stable meteoritic complex (Whipple, 1955). Objections to a cometary origin of the Zodiacal cloud were presented by Harwit (1963) without denting the cometary theory (Whipple, 1967). Since then, the Finson-Probstein theory of dust production has been applied successfully to dusty comets. As a consequence size distributions of dust particles have been deduced for Arend Roland, 1957 III, (Finson and Probstein, 1968), Seki-Lines, 1962 III, (Jambor, 1973), Bennett, 1970 II, (Sekanina and Miller, 1973) and Kohoutek, 1973 f. (Jambor unpublished). Only careful consideration of the size distribution of the dust from periodic comets can resolve the problem of the origin of the Zodiacal cloud. The following reexamines the production and history of the dust released from periodic comets using the Finson-Probstein theory and compares it to the size distribution of dust deduced from the above mentioned comets.

History of the Dust Released by Comets

Practically none of the dust released by new comets with near parabolic orbits stays in the inner parts of the solar system. The dust acquires hyperbolic orbits and is lost. Of the periodic comets with period less than 200 years we know that some are responsible for regular meteor showers. One can calculate the minimum size a dust grain released with zero initial velocity by an elliptical comet must have to have a non-parabolic or non-hyperbolic orbit and thus stay in the solar system. It can be shown that the eccentricity of the dust grain is

$$e_d = \left[1 + \frac{2p(1-\mu)}{\mu^2 r_c(t_c - \tau)} + \frac{e^2 - 1}{\mu^2}\right]^{\frac{1}{2}}$$

where p is the semi-latus rectum, e, the eccentricity of the comet, $r_c(t_c - \tau)$ is the distance of the nucleus from the sun at the time of release. If we set $e_d^2 = 1$, i.e., parabolic orbit, we have the condition:

$$2p(1-\mu) = (1-e^2)\, r_c(t_c - \tau)$$

or

$$1 - \mu = \frac{r_c(t_c - \tau)}{2a}$$

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where a is the semi major axis of the comet. To obtain an order of magnitude estimate, let us assume the dust is released mostly during the perihelion passage. We then obtain

$$1 - \mu = \frac{a(1 - e)}{2a} = \frac{1 - e}{2}$$

as the condition for escape. Table I shows the sizes of grains released by some important periodic comets. The average minimum size is 13.4 μm for ice and 5.3 μm for silicates. No particle smaller than this has a good chance of staying in the inner solar system. It can be shown that for parabolic or hyperbolic orbits, no single collision with a planet can perturb the orbit into an elliptical one (Everhart 1974).

Table I

Comet	Meteor Shower	Limit of $1 - \mu$	
1948 X11	α Cap	0.093	$1 - \mu$ average is
1852 III Biela	Andromeda	0.123	then: 8.86×10^{-2}
Encke	Taurids	0.076	$pd/Qr_p = 1.34 \times 10^{-3}$
Giacobini-Zinner	Draco	0.135	Ice: 13.4 μm
Halley		0.016	Silicates: 5.36 μm

Minimum size of the dust released by Periodic Comets which stays in the Interplanetary Medium.

The study of the dust released by some recent comets shows that the size distribution peaks at about one micron with distribution widths much larger for comets that come close to the sun, 1962 III, 1973 f, than for those that have perihelia at larger distances like comets, 1957 III and 1970 II. The former can release larger grains due to the more intense heating and subsequent faster release of gas, whereas the latter have proportionately fewer of these grains, of size 10 micrometers and above. Since periodic comets do not come very close to the sun, we can assume that their size distribution of grains is like those of comets 1957 III and 1970 II. In this case, only a very small fraction, about one tenth of the total at the most, of the grains released have the size required to stay in the Zodiacal cloud. If we take an extremely wide zeroth order logarithmic distribution of sizes, Kerker (1969), more characteristic of 1962 III and 1973 f, the area corresponding to the sizes which can be permanent members

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of the Zodiacal cloud is only about one-third of the total. This is shown in figure 1. This says that periodic comets contribute only a fraction of their dust to the cloud. In this context the Zodiacal cloud would be made up of particles larger than say 5 μm. This is in agreement with the determination of sizes from line shapes in the Zodiacal light spectrum (James and Smeethe, 1970). Results from scattering models are less conclusive (Giese, 1973). These scattering models, based on Mie calculations suffer from the contribution of many angles of scattering and distribution of sizes which all wash out fine structure and colors. Only in the Gegenschein region and very close to the corona are the contributions from angles few in number. Due to the difficulty of sorting out noise factors contributing to the low value of brightness of the Gegenschein, it appears that the best hopes of conclusive measurements of sizes of interplanetary dust lie with direct collection far from the earth or careful investigation of the F and K corona regions.

Mass Injection from Comets

Despite the loss of small particles, if enough large ones are ejected, comets can contribute to the Zodiacal cloud. The contribution of the comets to the Zodiacal cloud has been assessed from the point of view of mass supply compared to mass loss, (Whipple 1967). In this approach we must clearly distinguish between the particles which contribute to the continuum of the coma and tail and those that influence the total mass. The light scattering depends on the number density of particles of size comparable to the wavelength of light, it favors the small particles of 0.5 micron size. Given any size distribution of particles $g(\rho_d d)$ expressed in terms of the diameter d and density ρ_d, the most representative mass is given by (Finson and Probstein, 1968)

$$\pi \langle(\rho_d d)^3\rangle / 6 \rho_d^2$$

where the expression between brackets is the third moment of the distribution function:

$$\langle(\rho_d d)^3\rangle = \int_0^\infty (\rho_d d)^3 \, g(\rho_d d) \, d(\rho_d d) \; .$$

The mass contribution is not very sensitive to the smaller particles but weighted

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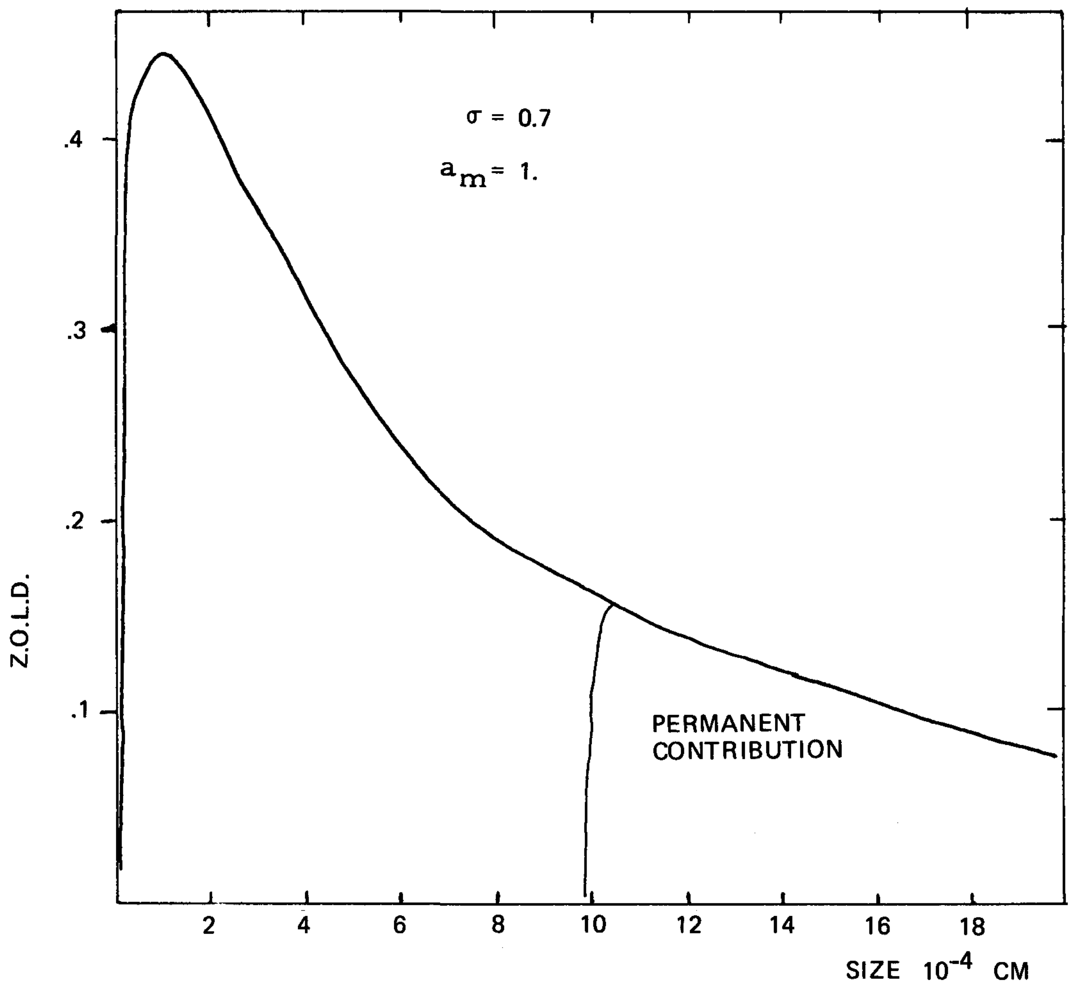

Figure 1 - A zeroth order logarithmic distribution (Z.O.L.D) with modal size a_m = 1 μm and scatter parameter σ = 0.7.

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towards the lower part of the distribution where larger particles are found. It is, therefore, not correct to base mass injection rates on calculations based on visual estimates of absolute magnitude. In the first place, the separation between emission and continuum must be done carefully, since bright comets can have low dust content. Secondly, considering the dust continuum only, a size distribution must be carefully calculated taking into account the dynamics of the particles, as revealed by the shape of the tail, which delineates the maximum and minimum sizes, together with the brightness distribution.
On the basis of such size distributions which determine the true ratio of large to small particles produced by the comet, mass production can be obtained. One can, therefore, not deduce a necessarily large mass injection from a bright visual display, nor can one estimate the previous brightness of a comet like Encke from the relics found in meteor streams. The presence of large particles detected as meteors coming from Encke does not necessarily mean an abundance of large particles high enough to replenish the Zodiacal cloud by itself.

Conclusion

We can eliminate all of the bright new comets from the ranks of the contributors to the Zodiacal cloud. Among the periodic comets, all particles of size much smaller than 10 μm are lost also. This leaves only the large particles as possible candidates. The situation at the present time does not allow us to draw any definite conclusions about the extent of the contribution of periodic comets. The amount of large particles released by Encke is not known. Only a careful analysis of the dust content of this comet can give the answer.

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