COLLISIONS AMONG INTERPLANETARY DUST GRAINS

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Abstract. Assuming that the zodiacal cloud is composed of two populations, the effect of collisions among the largest grains is investigated. It is found that the population of fragments is unable to explain the observed flux of submicron grains.

I. INTRODUCTION

Recently, Le Sergeant and Lamy (1978) re-analyzed space data on interplanetary grains, particularly lunar microcraters, and proposed an interpretation in terms of two components. Population 1 consists principally of large grains (radius > 2 μm) of density typical of silicates in nearly circular orbits while population 2 consists of small grains (radius < 2 μm) with typically metallic densities in hyperbolic orbits. We further showed that it is not possible to explain the origin of population 2 (identified with the so-called β-meteoroids) as collisional fragments of larger grains (population 1) being produced within 1 AU and subsequently repulsed by radiation pressure. The different physical nature of the two populations represents a first difficulty but the main argument relies on the non-conservation of mass flux : the mass influx at 1 AU is approximately three orders of magnitude smaller than the mass outflux. In this paper, we present the result of a detailed collisional model which fully supports our earlier conclusion : the flux of fragments from population 1 is much smaller than the observed flux of population 2 grains.

II. ASSUMPTIONS AND PROBABILITY OF COLLISIONS

The cumulative flux as obtained by Le Sergeant and Lamy (1979) is simplified in terms of three power laws (Figure 1). Following Zook and Berg (1974), population 1 grains are supposed to spiral slowly towards the Sun under the Poynting-Robertson effect ; they may be considered to travel in nearly circular orbits and to collide because of different inclinations. The situation is entirely different for population 2 grains

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for which the radial velocity is of the order of the orbital hyperbolic velocity. For the physical parameters of the fragmentation process, we rely heavily on the excellent laboratory simulations of Fujiwara et al. (1977). However, we distinguish only two regimes (rather than four) which depend upon the ratio of the projectile (s_2) and target (s_1) diameters :

i) the erosion regime for $s_2 < s_1/\gamma$
ii) the destruction regime for $s_2 \geqslant s_1/\gamma$
with $\gamma = 20 - 30$. The additional two regimes concern very narrow intervals of target/projectile size and may be neglected. It is then possible to calculate the number of collisions per unit time and, of greater interest, the probability of collision during the P-R lifetime and to reach the following conclusions :
i) the collisions among grains of population 1 are the only important process and always take place (probability = 1 during the P-R lifetime) ;
ii) this positive result is not sensitive to the choice of γ and of the inner boundary R_1 ($\simeq$ 0.1 AU).

III. EQUATIONS OF COLLISIONS AND FLUX OF FRAGMENTS

We outline below the procedure for calculating the flux of fragments. It is somewhat involved and will be published in detail in a separate paper. Following Dohnanyi (1976), we first calculate the number of fragments per diameter interval ds, per unit time, per unit volume, per unit ds_1 (target) and per unit ds_2 (projectile). This number is proportional to s^{-a} where a = 3.48 comes from the simulation of Fujiwara et al. (1977). We then integrate over s_1 and s_2 with different boundary values corresponding to the two regimes of collisions ; this gives the total number of fragments with diameter between s and s + ds per unit time, per unit volume. Next we perform an integration over space, taking into account a distribution of inclination, up to a distance of R_o = 1 AU. We then obtain the flux of fragments through the spherical surface of radius 1 AU in the ecliptic plane and integrate it to produce the cumulative flux to be compared with the observed curve (Figure 1) assuming that all fragments are ejected by radiation pressure on hyperbolic orbits. Out of four processes considered, only two are important : the destructive collisions among population 1 grains and of population 2 on population 1 grains. The various parameters – γ, the inner boundary R_o and the spatial dependence of the density of grains – have little importance on the final result. The two extreme cases are represented in Figure 1 and are well below the observed cumulative flux ; further, they are in agreement with the curve obtained from the conservation of mass flux.

IV. DISCUSSION

The difference between the two fluxes is so large that our present conclusion should not be affected by any possible variations of the parameters involved in the calculation. As we already discussed (Le Sergeant and Lamy, 1978), it is possible to consider that the mass influx of population 1 grains correspond to a mass loss rate. We arrived at a value of 2.8 x 10^4 g sec^{-1} to maintain population 1 in steady state. Assuming a grain albedo of 0.05, 7 short-period comets are required on the basis of the results of Sekanina and Schuster (1978) for Comet d'Arrest. The mass loss rate for population 2 amounts to 2.8 x 10^7 g sec^{-1} and is far more difficult to explain.

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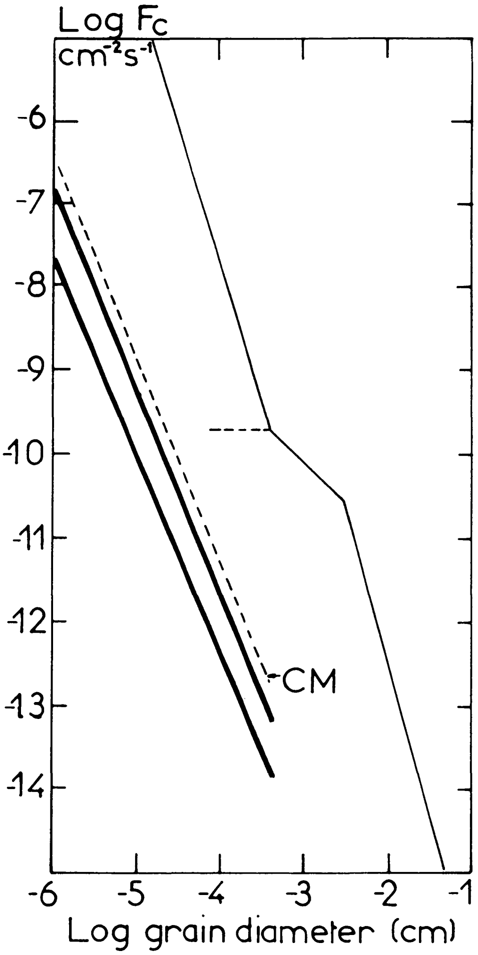

Figure 1. The observed cumulative flux (thin lines) and that of fragments (thick lines). The dotted lines correspond to the conservation of mass flux.

DISCUSSION

Zook: I have two comments. 1) If the particles are constructed as are the "Brownlee" particles, it is reasonable to expect the collision debris to have a size distribution similar to that of the individual grains of the Brownlee particles. 2) It is my recollection that the cumulative size distribution of the Morrison and Zinner data has an average slope in the micron to submicron range of -2 not -3 as you show. The value -3 is true only for a small size range.

Lamy: 1) The lunar microcrater data reveal a continuous distribution which we try to explain. 2) Yes; we have retained the highest possible slope.

Kresak: Did you take into account that each subsequent mass loss by the particle would reinforce the effect of direct radiation pressure, thus increasing the orbit size for Poynting-Robertson inspiralling?
Lamy: Your question applies only to the case of erosive collisions where the mass loss is very small - a microcrater is formed on the target grain. Therefore the change in radiation pressure should be negligibly small. Only for a narrow combination of target and projectile sizes will this effect be important. It was not included in our study but it should not change our results.

Leinert: How are your results different from the calculations which Dohnanyi presented at the Heidelberg conference and which result in higher flux values?
Lamy: We believe there is an error in the derivation of Dohnanyi resulting from an overestimation of the production of fragments after a collision.