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Modeling of Asteroidal Dust Production Rates

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ABSTRACT

The production rate of dust associated with the prominent Hirayama asteroid families and the background asteroidal population are modeled with the intent of using the families as a calibrator of mainbelt dust production. However, the dust production rates of asteroid families may be highly stochastic; there is probably more than an order of magnitude variation in the total area of dust associated with a family. Over 4.5 x 10^9 years of collisional evolution, the volume (mass) of a family is ground down by an order of magnitude, suggesting a similar loss from the entire mainbelt population. Our collisional models show that the number of meteoroids deliverable to Earth also varies stochastically, but only by a factor of 2 to 3.

INTRODUCTION

Since the discovery of the IRAS solar system dust bands, the contribution made by mutual asteroidal collisions to the background zodiacal cloud has received renewed attention. The interplanetary dust particle fluxes observed by the Galileo and Ulysses spacecraft indicate a population with low-eccentricity and low-inclination orbits (Grün *et al.*, 1992), consistent with an asteroidal origin of the particles. From computer simulations of the entry heating of large micrometeorites and comparison of the collisional destruction and transport lifetimes of asteroidal dust, Flynn (1992) has concluded that much of the dust collected at Earth from the interplanetary dust cloud is of asteroidal origin. Analysis of the IRAS dust bands using the SIMUL model of Dermott and Nicholson (1989) has established their connection with the prominent asteroid families and provides observational evidence of the delivery of asteroidal material to the Earth. Given that the Hirayama families contribute significantly to the interplanetary dust complex, we would expect that collisions among the background population of asteroids should contribute a substantial portion of the interplanetary dust in the zodiacal background. With their collisional origin well established, the prominent Hirayama families may provide us with a means of calibrating both the amount of dust to associate with the collisional destruction of a single asteroid and the amount of dust contributed to the zodiacal cloud by the mainbelt asteroids. Analysis using the SIMUL model gives the total effective areas associated with the IRAS dust bands, while ongoing analysis (Dermott *et al.*, 1992) will give the effective area of the entire zodiacal background. By comparing the observed ratio of family to background dust with the ratio determined from the models to be described in the following section, we will determine the extent of the contribution made to the background zodiacal cloud by mutual collisions within the mainbelt asteroid population.

MODELING DUST SOURCE PRODUCTION RATES

Description of the Model

The collisional model described here is a simplified form of the ACE model presented by Gustafson *et al.* (1992) with some modifications. Our model includes particles from 1 mm through the largest asteroidal sizes and in this early version ignores the effects of radiation forces on the small particles.

An asteroid of a given size is collisionally destroyed, its fragments following a power-law size distribution given by

$$dN = Br^{-p}dr,$$

where the constant B is determined by conservation of mass. The exponent p is taken to be somewhat larger than the equilibrium value of 2.511 (0.837 in mass units) in accord with laboratory experiments and the observed size-frequency distributions of the prominent Hirayama families, although it is recognized that in reality a single value may not well represent the size distribution at all sizes. The fragments are distributed among approximately 60 logarithmic size bins, the precise number depending upon the diameter of the parent asteroid. All particles are assumed to have the same density and impact strength. The characteristic size of each bin, determined from the total mass and number of particles in the bin, is used along with the assumed material properties of the particles and the assigned collision rate to associate a mean collisional lifetime with each size bin. The number of fragments distributed into smaller size bins in one timestep is calculated as in ACE, with the modification that only integer numbers of particles are allowed to be destroyed. For small size bins this procedure gives the same results as ACE as the number of particles involved is large. For the larger size bins considered in this model, however, the procedure more realistically treats the particles as discrete bodies and allows for the stochastic destruction of asteroid sized fragments.

To study the production rate and orbital evolution of dust sized particles (1 to 100 μm) we must account for the action of Poynting-Robertson drag and light pressure. The model described here, which does not include these effects and follows the collisional evolution of particles 1mm in diameter and larger, models the production rate of the immediate *sources* of asteroidal dust.

Model Results

Families. The preliminary results described here are indicative of more detailed and extensive calculations currently being run. The reader is referred to Durda *et al.*, (1992) for a more complete discussion of the collisional models, constraints upon the assumed collision parameters, and results. Figure 1a shows, as a function of time, the total geometrical cross-sectional area down to 1mm diameter particles associated with the collisional destruction of a 300 km diameter asteroid. As the dust production rate is proportional to the total area of the source particles, Fig. 1a is indicative of the production rate of dust sized particles and therefore the total area associated with the dust as a function of time. Following the initial, relatively smooth, decrease in area as the small particles created directly from the breakup of the parent body are destroyed, the production rate is seen to become more highly stochastic with time: while the overall area continues to decrease, the contribution to the total area from the destruction of intermediate size fragments becomes more significant. Over the age of the solar

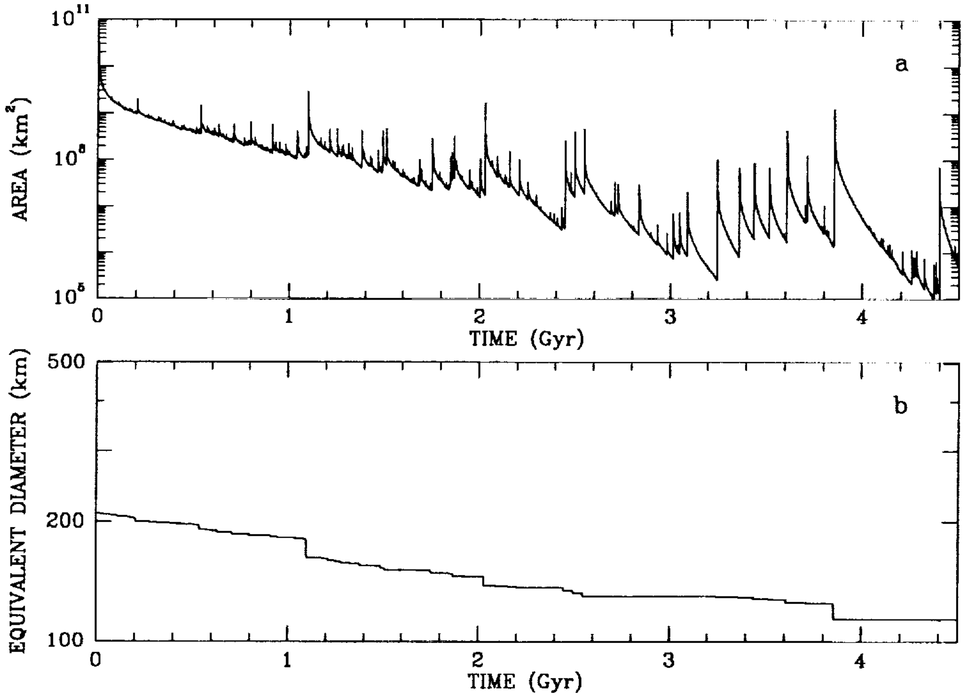

Figure 1. Modeled cross-sectional area to 1mm and equivalent diameter as a function of time for the fragments resulting from the collisional destruction of a 300 km parent asteroid.

system the observable volume of the family would be reduced by approximately a factor of ten, even assuming today's relatively placid collision rates. This is reflected in the decrease in an equivalent volume or diameter as illustrated in Fig. 1b. By extension, it is likely that the mass of the entire asteroid belt has been reduced by a similar factor by collisional grinding alone — a vast quantity of asteroidal dust was delivered to the inner solar system in the past.

The spikes in the dust source production evident in Fig. 1a are due to the breakup of small to intermediate size asteroids, some of which may be smaller than the diameter to which the actual families are complete with respect to discovery. Comparison of Fig. 1a and 1b illustrates that while the observable volume of the family may remain fairly constant and well-defined, the total dust area associated with the family during that time may vary by an order of magnitude or more. This effect becomes increasingly important with time as debris from the original breakup event decays away, to the extent that for very old families (or younger families made of weaker material) it may be difficult or impossible to predict the dust area to associate with the visible extent of large family members. It should be noted, however, that the magnitude of the variation exhibited in Fig. 1a is sensitive to the exponent p in the power-law size distribution of collision fragments. The spikes are subdued for values of p less than or equal to the equilibrium value.

We note that the production rate of small, meteoroid size particles is also stochastic. Preliminary models of the production of fragments larger than 1 meter in the region surrounding the 3:1 resonance indicate that the numbers of meteoroids potentially deliverable to Earth-crossing orbits varies within a factor of 2 or 3, thus supporting Wetherill and Chapman's (1988) statement that "there is a significant, but probably not dominant stochastic component" in the delivery of meteorites from the 3:1 Kirkwood gap.

Background Asteroids. The models of the background dust production are still being developed and extended. Initial calculations following the evolution of an asteroid belt beginning with a runaway-growth size distribution and a mass 15 times the present belt indicate a total area to 1 mm after 4.5 billion years of about 100 times that observed for the three prominent families. However, this model assumes a constant collision rate equivalent to the currently observed rate. The extended model adjusts the collision rate in a self-consistent manner dependent upon the projectile population.

CONCLUSIONS

The modeled dust source production rates for asteroid families may be highly stochastic. As such, dependent upon the current fragmentation regime of the prominent families, it may be difficult to use the IRAS observations of dust bands to place tight bounds on the collisional evolution and dust production rate of the asteroid belt as a whole. Over the age of the solar system the observable volumes of families are ground down by an order of magnitude. This suggests that collisional evolution has reduced the mass of the background population by a similar factor. The models also indicate a stochastic component in the delivery of meteorites to Earth. Although more refined models are being developed, the preliminary model results suggest a background to family dust production ratio sufficient to allow an asteroidal source of the zodiacal cloud.

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REFERENCES

Dermott S. F. and Nicholson P. D. (1989) IRAS dust bands and the origin of the zodiacal cloud. *Highlights of Astronomy*, **8** pp. 259–266.

Dermott S. F., Durda D. D., Gustafson B. Å. S., Jayaraman S., Xu Y.-L., Gomes R. S., and Nicholson P. D. (1992) The origin and evolution of the zodiacal dust cloud. These proceedings.

Durda D. D., Dermott S. F., and Gustafson B. Å. S. (1992) To be submitted to *Icarus*.

Flynn G. J. (1992) Large micrometeorites: Atmospheric entry survival, relation to mainbelt asteroids, and implication for the cometary dust flux. These proceedings.

Gustafson B. Å. S., Grün E., Dermott S. F., and Durda D. D. (1992) Collisional and dynamic evolution of dust from the asteroid belt. These proceedings.

Grün E., *et al.* (1992) Interplanetary dust near 1 AU. These proceedings.

Wetherill G. W. and Chapman C. R. (1988) Asteroids and meteorites. In *Meteorites and the Early Solar System* (J. F. Kerridge and M. S. Matthews, eds.), pp. 35–67. Univ. of Arizona Press, Tucson.