DEVIATIONS FROM THE STRAIGHT LINE: BUMPS (AND GRINDS) IN THE COLLISIONALLY EVOLVED SIZE DISTRIBUTION OF ASTEROIDS; D.R. Davis, (PSI, Tucson AZ); P. Farinella, P. Paolicchi, and A.C. Bagatin, (Univ. of Pisa); A. Cellino and E. Zappalà (Torino Observatory)

Dohnanyi [1,2] established that the size distribution of a collisionally relaxed population is a power-law with a -3.5 slope (incremental diameter), provided that: (i) collisional parameters are independent of size and (ii) there is no lower limit on the population size for shattering impacts. In the course of studying collisional effects over a wide range of asteroid sizes (cm up to hundreds of km range), we have investigated the consequences of relaxing the second condition, while maintaining the first one.

Consider the evolution of a population using a collisional model with a constant impact strength, no gravity and no cratering effects, but with a lower bound on the population. Figure 1 shows the evolved size distribution for three different starting populations: a) power law, initial slope = -4.0; b) power law, initial slope = -3.0; c) non-power law. In all cases, the evolved population shows a wave-like structure which differs from the straight power-law distribution found for the pure Dohnanyi case, i.e., one that meets both of the above conditions. However, the evolved populations shown in Fig. 1 do have a mean slope of -3.5, but with a superimposed "wave" structure.

The "wave" structure is produced by the small-size boundary condition as follows: i) for the smallest bin, only shattering collisions within the bin remove bodies from the bin; (ii) for the second smallest bin, projectiles from the smallest bin are an additional source for removing bodies from the bin, etc. Thus there is an increasing depletion rate with increasing size up to the size body \(D_1\) that can just be shattered by the smallest body in the population. Thus the population develops a steeper than -3.5 size distribution, and shows a relatively large depletion. Bodies larger than \(D_1\) are less depleted since there are fewer projectiles to shatter them due to the above depletion. Thus the population develops a shallower slope than -3.5 in this range. Repeating this pattern leads to development of the wave structure.

The wavelength of this structure depends on the impact strength of the population. As shown in Fig. 2, the wavelength varies inversely with the impact strength: the larger the strength, the shorter the wavelength.

Next we include gravity and cratering in the collisional model. Adding gravity to the model produces some changes, but the wave structure persists (Fig. 3a). Adding cratering produces a similar result, as does including both effects into the collisional model (Figs. 3b and 3c).

What are the possible implications of the result for asteroids? There is a real lower bound to the size distribution that is the result of radiation effects. For one, P-R drag produces a cutoff in the size distribution at about the cm size scale, although this is not a sharp size cutoff.

We included this effect in our simulation by removing small particles during a timestep by:

\[ \frac{\Delta N}{N} = \left(1 - e^{-\Delta t} \right) \]

where \(\Delta N/N\) is the fraction of particles of diameter \(D\) (meters) removed in time \(\Delta t\) (years); \(\tau = 4.5 \times 10^9 \cdot D \cdot \text{yrs.} \)

Including this loss mechanism into a simplified version of our asteroid collisional evolution program gives an evolved population with a wave structure superimposed on a quasi-power law distribution (Fig. 4). Hence we might expect that the size distribution of real asteroids in the small size range may differ from that predicted based on Dohnanyi's work. Further work is in progress to better understand how real size distributions may differ from the pure power-law case.

Figure 1. Evolved size distribution for three different starting populations: (a) power-law, initial slope = -4.0; (b) power-law, initial slope = -3.0; (c) non-power-law.

Figure 2. Effect of varying the impact strength on the structure of the first population.

Figure 3. Evolved population using an initial power-law with a -3.0 slope. Part (a) gravity only added to the collisional outcome mode; (b) crating only added; (c) both gravity and crating added.

Figure 4. Evolved population from an initial power-law with a -4.0 slope, over the size range from about 1 mm to 1000 km. Cratering, gravity and P-R drag are included. The dashed and dotted curves correspond to slopes -4 (dashed), -3.5 (dotted, diameters >1 m) and -3 (dashed, diameters <1 m), respectively.