SHORT PERIOD COMETS: PRIMORDIAL BODIES OR COLLISIONAL FRAGMENTS?

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We challenge the common assumption that most comets represent "primitive," unprocessed samples of the planetesimal population formed in the outer part of the primordial solar nebula. There are strong reasons for believing that short period comets come from the transneptunian Kuiper belt, which currently contains a population of objects ~10^3 times that of the main asteroid belt, spread over a volume ~10^3 larger and with relative speeds ~10 times lower. Stern [1] demonstrated that collisions among Kuiper belt objects (KBO) are significantly frequent. Therefore, like for the asteroids, the distribution of KBO has been affected by mutual impacts over solar system history.

We have simulated the collisional evolution of Kuiper disk bodies over timescales of billions of years using a numerical model developed originally for studying asteroid collisional history. Two modifications were made to the code to account for the specific characteristics of the KBO population. First, we adopted average collision rates and impact speeds appropriate to KBO orbits. Second, we assumed that KBOs are more fragile than asteroids, but still behave as moderately strong bodies in terms of their dynamic impact strength. Impact experiments using weakly bound aggregate bodies [2] and ice bodies [3] found that specific energies on the order of a few times 10^6 erg/g are needed to shatter such bodies. Hence, we have assumed an impact strength of 3×10^6 erg/cm^3, a factor 10 lower than the value adopted for asteroids.

The results for our baseline case run are shown in Fig. 1. The initial KBO population is assumed to be a power-law distribution at sizes smaller than 300 km and falls to zero for sizes between 300 km and 500 km. The orbital distribution has a mean eccentricity and sin i of 0.05, and impact speeds vary between 350 and 550 m/s. As seen from Fig. 1, the population at sizes larger than 100 km diameter is essentially unchanged over solar system history, because of the relatively low impact speeds found in this population. However, at sizes smaller than 100 km, there is increasing collisional depletion with decreasing size; for sizes ~20 km, the population is reduced by a factor of 10 from the initial one. The slope of the small size population is very close to -3.5, the equilibrium value for a collisionally relaxed population with size-independent collisional physics [4].

Radical changes in the starting population can result in a present population that is qualitatively different from that discussed above. For example, if the initial population consisted only of large bodies hundreds of km in size, then there would not have been enough collisional evolution to generate the population of small bodies that supply the short period comet population. Using again a starting population close to the current one at large sizes and following a power law for <300 km, we can estimate that the primordial small-size slope had to be more negative than about -2, otherwise the current reservoir of short period comets would be too small. Hence at the end of the accretionary phase there must have been a sizeable population of bodies down to at least a few tens of km in size. However, all the smaller (km-sized) bodies may well have been generated as fragments, as illustrated in Fig. 2. Here we show a case with all the primordial bodies larger than about 10 km in diameter. Again in the final population all the bodies larger than about 70 km are survivors, but the disruption of smaller ones yields a "tail" of collisional fragments sufficient to supply the current comet reservoir.

Varying the collisional parameters (impact strength, strength scaling with size, ejecta energy partitioning coefficient, etc.) resulted in changes similar to those described above. Changes that produce collisionally weaker bodies showed a greater degree of collisional evolution, while those that produced stronger bodies had less evolution. All cases, though, led to a collisionally relaxed population at sizes smaller than about 25 km.

Thus, a fairly general conclusion from our collisional modelling work is that the population of KBOs larger than about 50-100 km diameter is not significantly altered by collisions over the age of the solar system. On the other hand, smaller objects currently present in the KBO population are mostly fragments undergoing a collisional cascade, with a size distribution index close to the -3.5 value which corresponds to an equilibrium collisional cascade if the collisional response parameters are size-independent (as we had assumed). If short period comets come from the Kuiper belt, then most of them (possibly some 90%) are not primitive planetesimals, but fragments from larger parent bodies, such as those currently observed in the Kuiper belt.

Actually, as a by-product of the collisional process we have found that about 10 km-sized fragments per year are currently produced in the inner Kuiper belt at ejection speeds of 10-100 m/s, similar to those inferred for asteroids. As a consequence, these fragments have semimajor axes about 0.1-1.0 AU different than their parent bodies. This is sufficient to cause at least a few percent of them (say, 0.2/yr) to fall into the resonant "escape routes" from the Kuiper belt [5] and to chaotically evolve into the planetary region of the solar system. This is roughly in agreement with the required flux to replenish the short period comets, which have an estimated population (including extinct/dormant nuclei) of $2x10^4$ bodies and a mean dynamical lifetime of about $3x10^5$ years [6]. Thus about 0.06 comets per year are needed to maintain this population. If one-third of the Kuiper belt fragments that fall into a resonant escape routes become Jupiter family comets, this is adequate to maintain the population. Therefore, KBO collisions are a sufficient mechanism to supply the short period comets, exactly like collisions in the main asteroid belt can supply near-Earth asteroids and meteorites. There is some other independent evidence for a collisional processing of short period comets: (i) their irregular, triaxial shapes resemble those of fragments produced in breakup events [7]; (ii) the variety of colors observed among Centaur and Kuiper belt objects can be interpreted as a result of a varying degree of collisional alteration and/or resurfacing [8].

References: [1] Stern, S.A. (1995), *Astron. J.*, in press; [2] Ryan, E.V. (1991), *Icarus* **94**, 283; [3] Lange, A., and Ahrens, T.J. (1985), *LPSC XVI*, 1298; [4] Dohnanyi, J.W. (1994); [5] Morbidelli, A. (1996), *Icarus*, in press; [6] Levison, H.F., and Duncan, M.J. (1994), *Icarus* **108**, 18; [7] Jewitt, D., and Meech, K. (1984), *Astron. Astrophys.* **138**, 464; [8] Luu, J.X., and Jewitt, D.C. (1995), submitted to *Astron. J.*

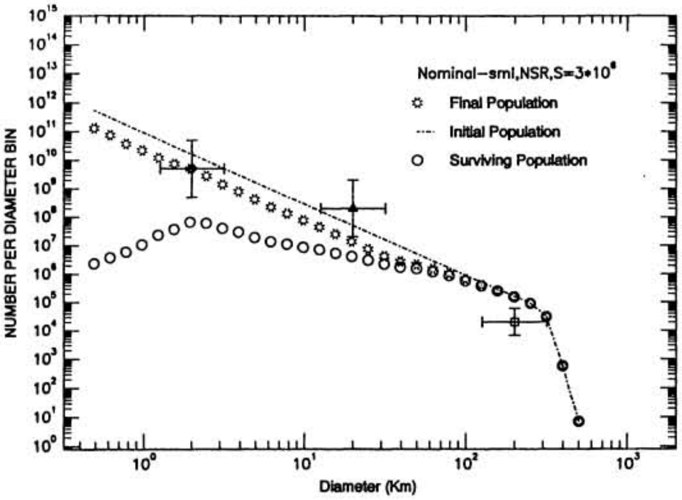

Figure 1. The collisionally evolved population of KBO after 4.5 Byr (asterisks), starting from a hypothetical initial population having a power law size distribution with -3.5 index for diameters <300 km (dash-dotted line). The number of "survivors" from the original population (open circles) is also plotted. The bars correspond to observational constraints and theoretical estimates; with increasing size, points are the Kuiper belt population inferred from the influx of short period comets, the HST survey results, and the ground-based discoveries. The assumed uncertainties span a factor of 10 in the number of bodies, a factor of 2 in their sizes.

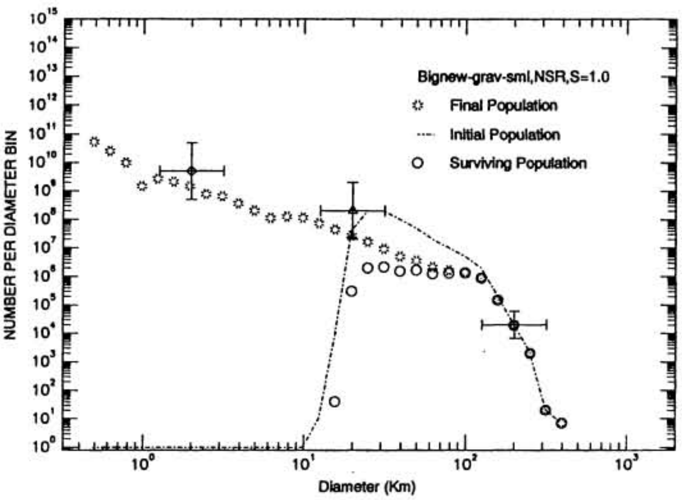

Figure 2. The same as Fig. 1, but for an initial population close to the current one at large sizes and containing no bodies smaller than about 10 km in diameter. Although the large bodies are never disrupted by collisions, a "tail" of small fragments is developed, sufficient to fill the comet reservoir enough for yielding the observed short period comet influx.