PLUTO'S FAMILY: DEBRIS FROM THE BINARY-FORMING COLLISION IN THE 2:3 RESONANCE?. S. A. Stern (astern@swri.edu), R. Canup, D. D. Durda, *Southwest Research Institute, Boulder CO 80302, USA.*

The Pluto-Charon binary is commonly believed to have been formed via a giant impact (e.g., McKinnon 1984; Hildebrand 1985; Burns 1986; McKinnon 1989; Stern 1991; Stern *et al.* 1997). We hypothesize that some fraction of the cohort population orbiting with Pluto in the 2:3 mean motion resonance (MMR) of the Edgeworth-Kuiper Belt (EKB) is debris derived from the Pluto-Charon binary formation event. Several lines of evidence point to the plausibility of this hypothesis.

Consider first the intriguing circumstantial evidence contained in the inclination distribution of the 12 multiple opposition Edgeworth-Kuiper Objects (EKOs) in the 2:3 MMR (Fig. 1; http://cfa-www.harvard.edu/iau/lists/TNOs.html). Eight such objects lie in orbits with inclination less than 7 degrees ($\sin i < 0.12$). However, all 4 remaining objects lie in a clump between 12 and 20 degrees. No 2:3 MMR objects have as yet been identified with inclinations between 7 and 12 degrees, giving the appearance of a bimodal population. The mean inclination of the 4 objects in the ''high inclination subgroup'' is 16 degrees: within 1 deg of the inclination of Pluto's orbit. Although it is possible that non-family, ''background'' EKOs could have evolved to Pluto-like inclinations through dynamical effects alone (Levison and Stern 1995), such an inclination distribution is also what might be expected from a family-forming collision.

The resemblance of the size distribution of Pluto, Charon, and the four 2:3 MMR EKOs in the ''high inclination subgroup'' to the size distributions of the Hirayama asteroid families further suggests the existence of a Pluto ''family.'' Tanga *et al.* (1999) have modeled the size distributions of asteroid families, including the finite geometrical effects of fragment packing within the volume of the parent body, and have been able to reproduce the observed features of the major family size distributions, including the shallowing of slopes at smaller size, which are usually attributed to survey incompleteness effects. The Pluto/Charon/2:3 MMR EKO size distribution is consistent with the distribution of fragments generated by large catastrophic impact events. To better illustrate this, Fig. 2 shows the cumulative number of objects versus diameter for the 2:3 MMR EKO population, compared to the size distributions of the Eos, Flora, Koronis, Themis, and Vesta asteroid families. The EKO numbers used here have been corrected for incompleteness in the ecliptic surveys of the EKB (Jewitt *et al.* 1998). The 2:3 MMR EKO population and the asteroid family distributions are strikingly similar, including the steep slopes and often significantly larger largest remnants. This provides suggestive evidence that the population of objects in the 2:3 resonance may have been produced in the collision event that formed the Pluto-Charon binary.

This (albeit circumstantial) evidence leads us to ask, in turn, whether the Pluto-Charon forming collision could, in principle, have injected a substantial amount of material into heliocentric orbit.

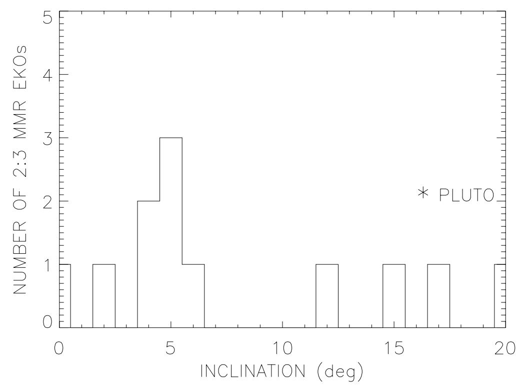

Figure 1: Inclination distribution of the 12 multiple opposition Edgeworth-Kuiper Objects in the 2:3 mean-motion resonance.

Unlike the Earth-Moon system formation event (e.g., Cameron 1997; Cameron & Canup 1998), simulations of the impact believed responsible for the formation of the Pluto-Charon have yet to be performed. However, recent studies using hydrodynamic methods to simulate impacts between rock or ice density bodies have yielded scaling relationships that can be utilized to obtain preliminary estimates relevant to this work.

Benz & Asphaug (1999) have recently completed a comprehensive survey of impact outcomes using SPH to simulate impacts throughout the strength and gravity regimes, including target sizes up to 100 km in radius. They determine an expression for Q_D^* -- the specific energy needed to disrupt and disperse a target so that the largest remaining fragment is one-half the mass of the original target -- given by $Q_D^* = Q_o R_{tar}^a + B\rho R_{tar}^b$, where R_{tar} is the target or parent body radius in cm, ρ is density, and Q_o, B, a and b are empirical parameters determined for ice or rock as a function of impact velocity. In addition, Benz & Asphaug derive a relationship between the mass of the largest surviving fragment, m_{lr}, and the ratio of (Q/Q_D^*), where Q is the specific energy of a given impact. By combining these scaling relations, we can estimate what impact energy would be needed to yield Pluto as the largest remaining fragment while also ejecting an amount of material sufficient to account for a significant fraction of the 2:3 MMR population. For $(m_{imp} + m_{tar}) \approx$ 3-5 M_{Pluto}, and $m_{imp}/m_{tar} \approx$ 0.1-0.3, impact velocities ~2.5-3 km/sec are required to yield Pluto as the largest fragment, or $v_{imp}/v_{esc} \approx$ 1.8-2. These impact velocities correspond to orbital eccentricities of ~0.4. Assuming the median impact parameter for randomly oriented impacts, all of these collisions provide more than enough collisional

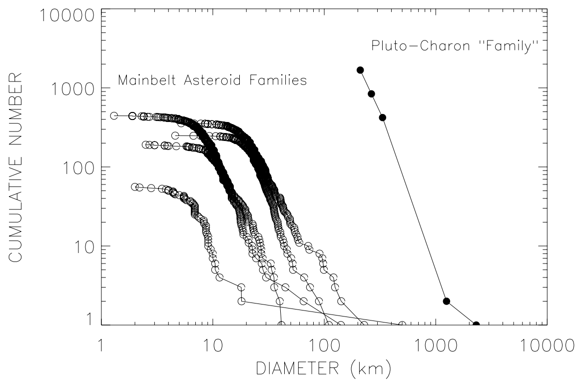

Figure 2: Size distribution of the Pluto "family" compared to the size distributions of five prominent main-belt asteroid families.

angular momentum to account for the current total angular momentum of the Pluto-Charon system.

Clearly these are simple estimates that cannot indicate whether the binary Pluto-Charon pair would actually result from such a collision, what the probability of capture of ejected debris into the 2:3 MMR would be, or what fraction of the collisional angular momentum would be retained by the Pluto-Charon pair. Answering these questions will require numerical simulations specific to the hypothesized Pluto-Charon forming impact which we are now planning.

However, these simple considerations do show that it is *plausible* that the giant impact believed to have formed the Pluto-Charon binary *could* have injected 1 M_{Pluto} or more of material into heliocentric orbit outside the binary itself. Since it is estimated that ≈10% of the mass of the present-day EKB resides between 30 and 50 AU (Jewitt *et al.* 1998), i.e., some ∼4-20 M_{Pluto}, it is possible that a substantial fraction of the 2:3 MMR population are members of a Pluto family.

If that is indeed the case, then there may be additional observables, including surface colors and compositions that link some members of the 2:3 MMR with Pluto-Charon.

Such a family would not only be a first in the EKB, but would also provide a further link between EKB and asteroid belt studies. It could also provide a new set of constraints on the Pluto-Charon forming event.

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