ON THE NUMBER OF PLANETARY BODIES CREATED IN THE OUTER SOLAR SYSTEM; Alan Stern, University of Colorado, Boulder CO 80309.

A natural consequence of the accumulation stage of planetary formation is the scattering of planetesimals during the accretion epoch. In the outer Solar System, such scattering contributed to the formation of the Oort Cloud (with an orbital semi-major axis distribution $10^3<a<5\times10^4$ AU) and the Kuiper Disk (30<a<500 AU). We suggest here that in addition to comets, a potentially large number of planetary bodies in the size class near 1000 km may have also been scattered into the Kuiper Disk and Oort Cloud. This hypothesis implies that the present population of planets in the outer solar system is much larger than previously recognized.

Several lines of evidence are identified which indicate that a large population of small (10^3 km class) planets existed in the 20-50 AU region during the formation epoch for Uranus, Neptune, and Pluto. We show that plausible values of the probability of (i) tipping Uranus, (ii) creating the Pluto-Charon binary, and (iii) placing Triton in its retrograde orbit about Neptune each require a substantial population ($10^2<N<10^{3.5}$)of 1000 km sized bodies in the 20-50 AU region when these events took place. Although future, more detailed modelling may improve on the spread of population estimates presented in this first analysis, it is already clear that the likelihood of occurring in an efficient way (i.e., with only the three 1000 km bodies we see today, Triton, Pluto, and Charon) is extremely small.

The evidence that a substantial number of 1000 km bodies existed during the accumulation epoch of the outer planets would appear to be at odds with modelling results which indicate Neptune and Uranus were runaways from a power law distribution of planetesimals that produced very few bodies larger than a few hundred kilometers [1].

Our simulations, using equilibrium random velocities developed according to [2], indicate the primordial population of 1000 km bodies was likely dynamically removed from the 20-50 AU region during the accumulation of Uranus and Neptune. The presence of the Oort Cloud and Kuiper Disk attests to such a period of removal for a population of much smaller objects. Because 1000 km objects scatter as well or better than comets, many of these small, primordial planets likely exist today in the Kuiper Disk and Oort Cloud, with the Oort Cloud population probably dominating. Triton, Pluto, and Charon, however, owing to their uniquely stable dynamical niches, likely represent the only relics of this ancient population which are permanently-preserved in the 20-50 AU region.

We examined three potential methods for the detection of 10^3 km objects in the Kuiper Disk region: searches for their reflected light, searches for their IR emission, and searches for their gravitational perturbations on spacecraft. We found that the present detection limits are only constraining inside 80 AU. Because dynamical models of the Disk [3,4] indicate the region inside 50-70 AU is highly unstable to loss by planetary perturbations, the number of comets and 10^3 km bodies there is not expected to be large. Optical and IR sky surveys offer the capability to detect or severely constrain the presence of such objects to >100 AU presently, and to >400 AU with systems and techniques planned for the next decade.

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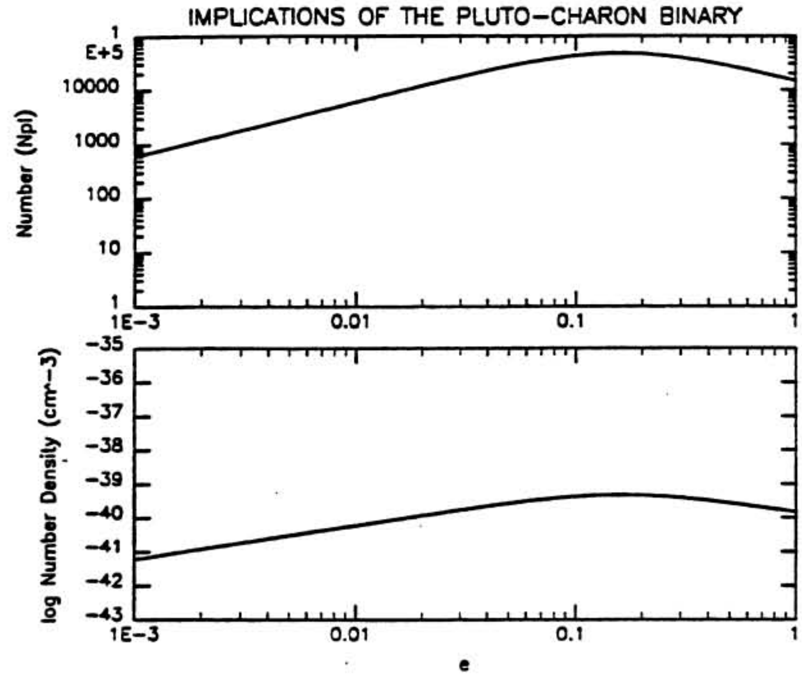

Figure 1. Shown here are the predicted number density and number of Pluto-like objects required in the 30-50 AU zone in order to achieve a unit probability of a Pluto-Charon impact over 4.5 x 10^9 years. This result is parameterized as a function of the mean random eccentricity (⟨e⟩) of the ensemble of hypothesized primordial Pluto-Charon class bodies. Note that the population number density and number scale directly with *P* and inversely with *t*.

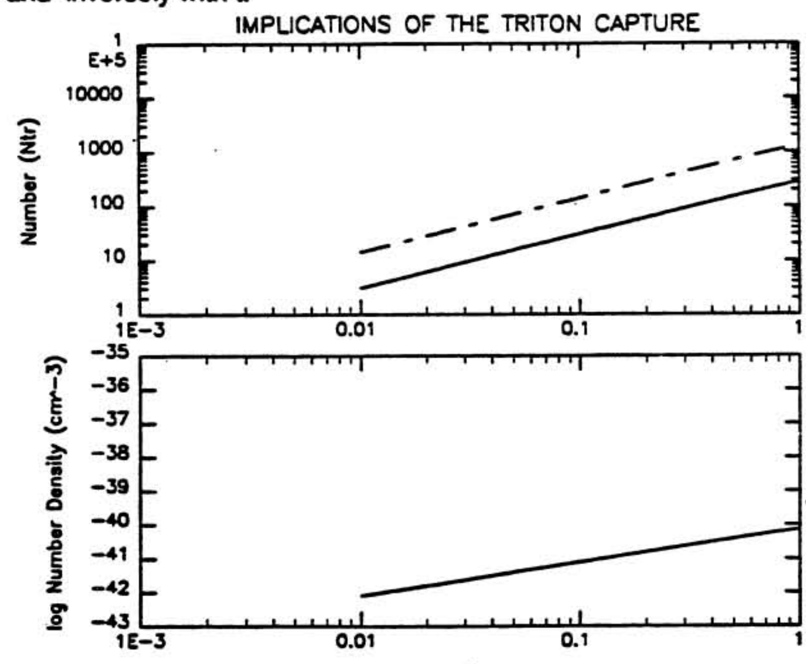

Figure 2. Shown here are the predicted number density and number of Triton-like objects required in the Neptune accretion zone 30-50 AU zone in order to achieve a unit probability of a Triton capture over 5 x 10^8 years. A capture efficiency of $\eta = 10^{-2}$ was assumed here. Low capture efficiencies, as suggested by McKinnon [5] and Goldreich, et al. [6] would increase the derived estimate of N. This result is parameterized as a function of the mean random eccentricity (⟨e⟩) of the ensemble of hypothesized primordial Triton-like bodies relative to Neptune's orbit. A minimum value of ⟨e⟩ = 0.01 was adopted, owing to Neptune's intrinsic eccentricity.