KUIPER BELT OBJECT ENCOUNTERS WITH THE PLUTO-CHARON BINARY: A MECHANISM FOR EXCITING CHARON’S ECCENTRICITY, H.F. Levison & S.A. Stern (Southwest Research Institute, Boulder, CO).

Recently, Tholen & Buie have reported astrometric evidence for a significant orbital eccentricity of Pluto’s satellite Charon, with a likely value near 0.003 [1]. Previously, all estimates of Charon’s eccentricity were consistent with zero [2]. Below, we demonstrate that this non-zero eccentricity in the Pluto-Charon system can be induced by gravitational interactions with other Kuiper belt objects.

The newly-reported eccentricity of Charon’s orbit has been considered surprisingly large because i) the tidal spin-down time of the Pluto-Charon binary (PCB) is short (~ 9 Myr) compared to the age of the solar system, ii) solar perturbations induce an eccentricity of only ~ 5 x 10^-9 [3], and iii) Charon’s equilibrium orbital eccentricity due to physical collisions with Kuiper belt comets [3] is near 10^-5. Our own simple estimates for inducing an eccentricity of order 0.003 by the impact of a large (R=100 km) Kuiper belt object on Pluto or Charon failed to be plausible because, although such a collision can be sufficiently energetic to induce the requisite eccentricity, the capture cross section for such events is so low that the population of large impactors exceeds modern Kuiper belt models [4,5] by factors of 300-1000. This finding is similar to that reached by Peale [6].

As an alternative to physical collisions, we have now investigated the effects of close scattering encounters between Kuiper belt bodies and the PCB. Such encounters can induce an eccentricity in the binary orbit owing to the differential forces acting on Pluto and Charon during the encounter. Our initial results have been promising.

In this preliminary study, we modelled the PCB as two point masses with a semi-major axis of 19,600 km and an initial eccentricity of zero. Solar and planetary perturbations were ignored. We then constructed a plausible Kuiper belt model with objects distributed in radius between 20 and 330 km with a differential population power law exponent of -3. The total number of objects in this size range within 50 AU of the Sun, $N_{KB}$, was a free parameter in our calculations. This Kuiper belt model was used to compute average number densities in the disk, from which we computed average encounter times for impact parameters (relative to the system barycenter) of up to twice the semi-major axis of the binary. We assumed the average asymptotic encounter speed between the Pluto-Charon binary and Kuiper belt objects is 1 km/sec. A Monte Carlo simulation was used to create impact parameter statistics. We also assumed that i) the encounter asymptotes are isotropic on the sky as seen from the PCB, ii) the encounter interactions can be treated by the impulse approximation, and iii) the intruding Kuiper belt body follows an unaccelerated, rectilinear path through the PCB. Between events, the eccentricity was allowed to decay as $e(t) = e_0 \exp(-t/\tau)$, where $t$ is the elapsed time since the most recent encounter and $\tau$ is the eccentricity damping timescale due to tidal perturbations. We took $\tau = 9 \times 10^6$ years [3].

Figure 1 shows the distribution of eccentricity for three different values of $N_{KB}$. Our crude calculation indicates that $N_{KB}$ is between $3 \times 10^5$ and $3 \times 10^6$, with a preferred value of $3 \times 10^5$. Extrapolating this size distribution down to cometary sizes ($\approx 1$ km), we would predict that there are $\sim 10^{10}$ objects in the Kuiper belt within 50 AU of the Sun. This value is consistent with estimates of the number of comet-sized Kuiper belt objects necessary to produce the observed Jupiter-family comets [3,4]. The temporal behavior of PCB’s eccentricity as a function of time for the run with $N_{KB} = 3 \times 10^7$ is shown in Figure 2. Notice that Charon has a median eccentricity near 0.003 (which was determined by our choice of $N_{KB}$), but also displays frequent excursions to much larger and smaller values.

In summary, we have identified a previously unexplored mechanism for inducing eccentricity in the Pluto-Charon binary. This purely gravitational mechanism results from the cumulative differential effect of numerous encounter events between the PCB and Kuiper belt objects. We found that we can easily produce PCB eccentricities of the order of 0.003. For our assumed model of the Kuiper belt, we found that it contains $\sim 3 \times 10^7$ objects between 20 km and 330 km within 50 AU of the Sun, but this result is somewhat sensitive to other free parameters in the model. Although the techniques we employed here are crude, we are encouraged by these early results, which we plan to improve upon with higher-fidelity simulations.
Kuiper Belt Object Encounters: Levison and Stern

Figure 1 — The fraction of time that the Pluto-Charon binary has an eccentricity greater than a particular value, as a function of that value for three different Kuiper belt population, $N_{KB}$ in a size range of 20 — 330 km. The dashed line indicates the reported value of PCB's eccentricity [1].

Figure 2 — The temporal variation of the Pluto-Charon binary's eccentricity for $N_{KB} = 3 \times 10^7$.