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MAPPING THE STABILITY REGION OF THE 3:2 NEPTUNE-PLUTO RESONANCE.

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Pluto and Charon are most likely the remnants of a large number of objects that existed in the Uranus-Neptune region at early epochs of the solar system [1]. Numerical integrations have shown that, in general, such objects were ejected from the planetary region on timescales of $\approx 10^7$ years (cf. [2]) after Neptune and Uranus reached their current masses. It is thought that the Pluto-Charon system has survived to current times without being dynamically removed in this way because it is trapped in a set of secular and mean motion resonances with Neptune (cf. [3]). The best-known Pluto-Neptune orbit coupling is the 3:2 mean motion resonance discovered almost 30 years ago by C. Cohen and E. Hubbard [4]. These workers showed that the resonance angle, $\delta \equiv 3\lambda_P - 2\lambda_N - \tilde{\omega}_P$, where $\tilde{\omega}_P$ is the longitude of perihelion of the Pluto-Charon system, and λ_N and λ_P are the mean longitude of Neptune and Pluto-Charon respectively, librates about 180° with an amplitude, A_δ, of 76°.

We report here on a numerical simulation project to map out the stability region of the 3:2 resonance. The results of these simulations are important to understanding whether Pluto's long-term heliocentric stability requires only the 3:2 resonance, or whether it instead requires one or more of the other Pluto-Neptune resonances.

Our study also has another important application. By investigating stability timescales as a function of orbital elements, we gain insight into the fraction of orbital phase space which the stable 3:2 resonance occupies. This fraction is directly related the probability that the Pluto-Charon system (and possibly other small bodies) could have been captured into this resonance.

In the simulations we report here, we employed a numerical integrator to evolve the orbits of massless test particles in and around the 3:2 resonance under the direct gravitational influence of Uranus and Neptune. The test particles were followed using the simplectic integration scheme described in [5]. The motions of Uranus and Neptune were calculated analytically from a synthetic secular perturbation theory using the four dominant perihelion precession frequencies discussed in [6]. Thus, although Jupiter and Saturn were not explicitly included in the simulation, their effect on the orbits of Uranus and Neptune are included. This approach has been shown to give good statistical agreement with techniques that include direct integration of the planets for particles in this region [7]. The integrations lasted 2 billion years. The particles were followed until they suffered a close approach to either Neptune or Uranus, at which time they were assumed to be removed from the resonance.

Our goal is to determine whether the orbit of a test particle is stable over a significant fraction of the age of the solar system as a function of A_δ, and its initial inclination and argument of perihelion, i_0 and ω_0 respectively. We plan to study orbits with $A_\delta < 180°$, $i_0 < 180°$, $0 < \omega_0 < 90°$, and an initial eccentricity equal to the current eccentricity of Pluto, 0.248.

We present here a preliminary report on this study. Over 160 test particles have been integrated in order to sample important aspects of the orbital element space. As of this time we have studied the regions of $A_\delta < 180°$, $i_0 \leq 35°$, with ω either 0 or 90°.

First we present the results for our most well studied case, particles with $i_0 = 17.2°$, which is the inclination of Pluto. Figure 1 shows the removal times for these particles as a function of their libration amplitude, A_δ. The open and filled circles represent objects with $\omega_0 = 0$ and 90° respectively. If a symbol is on the dotted line then the particle survived for the length of the integration (2 billion years). The largest A_δ that survived is approximately 80°. Interestingly, the Pluto-Charon system has $A_\delta = 76°$.

An examination of the individual orbits shows that the argument of perihelion circulates rather than librates. Since ω of our particles circulate, there should be no fundamental difference between the $\omega = 0$ and $\omega = 90°$ runs, and this is what is observed. The argument of perihelion of the Pluto-Charon system librates around 90° so that it is above the orbital plane of Neptune when it is at perihelion ([8]). It has been argued that this aids in the stability of its orbit. Our results show that this may not be necessary. Indeed, we find that objects in the 3:2 resonance with Neptune that have the same A_δ and inclination as the Pluto-Charon system seem to be stable for at least 2 billion years, even if they are not protected by the libration in ω.

Preliminary results for objects with different inclinations are as follows. We find that the maximum libration amplitude that is stable, $A_{\delta,max}$ is not a strong function of either i_0 or ω_0. For most values of i_0 and ω_0, $A_{\delta,max} \approx 90°$. The only exception appears to be for a small region near $\omega_0 = 90°$ for $i_0 \gtrsim 20°$. For this region all orbits appear to be short lived, having lifetimes less than 10^8 years. The explanation for this is being investigated.

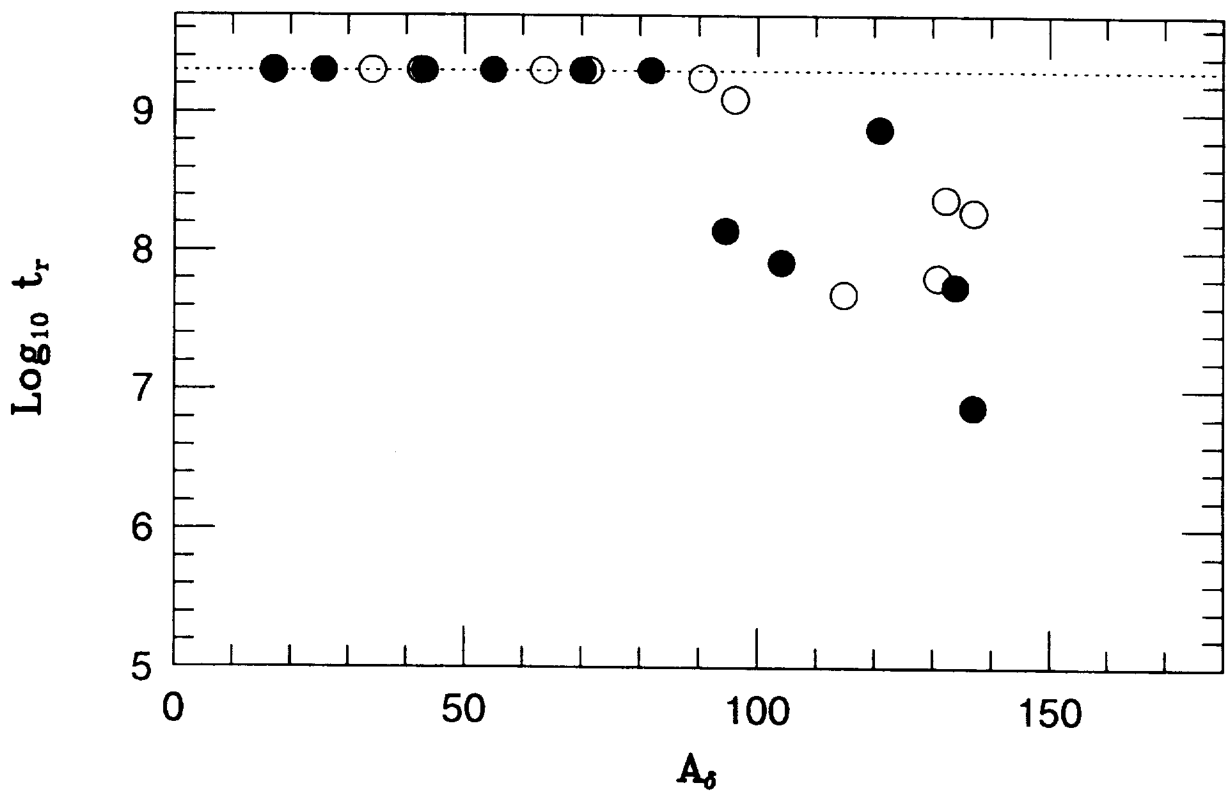

Figure 1 - The removal times of massless test particles in the 3:2 resonance with Neptune. There initial inclination is 17.2°, the initial argument of perihelion is either 0 (open circles) or 90° (filled circles).

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