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The Evolution of the Pluto System

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Abstract

A giant impact origin of Pluto's large satellite Charon leaves Pluto initially spinning rapidly and Charon in a close, eccentric orbit[1]. With coefficients J_2 and C_{22} in the gravitational fields of both bodies included, we follow the evolution of the system with tidal models that demonstrate spin-orbit resonance capture and escape and damped librations while conserving angular momentum. We use these tidal evolution models to investigate the conjecture that the small satellites, Nix and Hydra, were formed simultaneously with Charon and were pushed to their current positions while locked in 4:1 and 6:1 mean motion resonances with Charon. We demonstrate that a new phenomenon of simultaneous capture of a test particle into several resonances at each of the 5:1, 6:1 and 7:1 commensurabilities allows the stable expansion of the test particle orbits but not at the 4:1. This latter failure and the fact that conditions necessary for simultaneous captures will not prevail destroys this means of stable orbit expansion. With plausible values of J_2, C_{22} and finite masses for Nix and Hydra, there were no stable expansions for more than a million sets of initial conditions. Nix and Hydra cannot have their orbits expanded through resonant transport. The New Horizons mission may constrain an alternative origin.

1. Introduction

The most likely origin of the Pluto-Charon pair is a glancing collision of an object somewhat larger than Charon with the Pluto precursor leaving Pluto rapidly spinning and Charon in a close eccentric orbit with semimajor axis near $4R_P$ (Pluto radii) [1]. Subsequent tidal evolution expands Charon's orbit to its current value near $17R_P$ and damps the orbital eccentricity while slowing both Pluto's and Charon's spins to a common value that is synchronous with the orbital motion. One of two tidal models used to follow this evolution assumes an equilibrium tide whose maximum is located at the position of the sub-satellite point on the tidally distorted body a short time Δt in the past—equivalent to the dissipation parameter $Q \propto 1/\mathrm{frequency}$ if Δt is constant. The other model assumes a constant Q. The discovery of the satellites Nix and Hydra on nearly circular orbits [2] pose special problems in understanding their origin in the context of the expansion of Charon's orbit.

2. Expansion of Charon's orbit

In the evolution of the Pluto-Charon system from the above initial condition to the final state, we consider both $J_2 = C_{22} = 0$ and, separately, hydrostatic values of J_2 for Pluto and constant $C_{22} = 1.0 \times 10^{-5}$ for both Pluto and Charon. The zonal coefficient J_2 has a negligible effect on the overall evolution of Pluto and Charon, but it has a profound effect on the evolution of the Nix and Hydra orbits (see below). Conservative torques from the axially asymmetric Charon while in a spin-orbit resonance can prevent growth of eccentricity that would otherwise lead to instability.

The eccentricity e_C of Charon's orbit during the evolution is controlled by the relative dissipation in Charon and Pluto, where a judicious choice of the ratio can keep Charon's eccentricity near its initial value until the final relaxation into the equilibrium state. The diverse routes to the final state depend critically on this ratio, on the initial Charon eccentricity, on the tidal model and on C_{22}. Fig. 1 shows an example of the ratios of the spins of Pluto and Charon to the orbital mean motion for the constant Δt model, where e_C remained near the initial value of 0.3 until the final relaxation to equilibrium.

3. Nix and Hydra

The proximity of Nix and Hydra to the 4:1 and 6:1 mean motion commensurabilities with Charon led Ward and Canup [3] to propose expansion of the Nix and Hydra orbits while trapped in corotation resonances (not involving e_N or e_H, the eccentricities of Nix and Hydra respectively) at the respective commensurabilities with Charon's motion. The growth of orbit eccentricities of Nix and Hydra to instability if

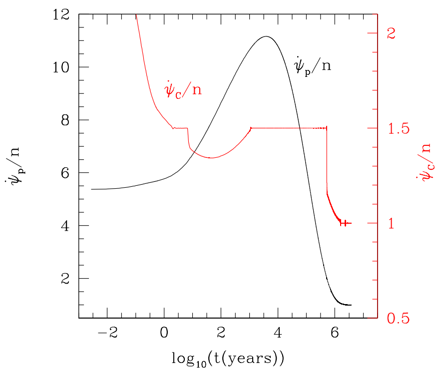

Figure 1: An example of the evolution of the ratios the spins of Pluto and Charon to the orbital mean motion for the constant Δt model. Note captures and escapes of Charon at the 3:2 spin-orbit resonance, initial slowing of Charon's approach to synchronous rotation by "pseudo synchronous" rotation as e_C decreases, and damped libration about the synchronous resonance.

trapped in any other single resonance at these respective commensurabilities required confinement to the corotation resonances. This scheme of expansion did not survive the scrutiny of Lithwick and Wu [4].

For Pluto's $J_2 = 0$, we found that a test particle that started outside the 5:1, 6:1 or 7:1 mean motion commensurabilities with Charon could be trapped simultaneously into several or all of the resonances at these commensurabilities as Charon's orbit expanded. The stable expansion of the orbit while trapped in the resonances without excessive eccentricity growth ensued. This had the promise of avoiding the eccentricity growth of the orbits of the small satellites that occurs when captured in any single resonance except the corotation resonance, and of avoiding the problem of the extremely low probability of capture into and subsequent expansion within only the corotation resonance. The final eccentricity of the test particle is large in the successful evolutions except in one single case. The rare capture into multi-resonances at the 4:1 commensurability always became unstable before completion of the evolution. Finally, a necessary condition for capture into and simultaneous migration within several resonances is that Charon's and the small satellite orbits remain aligned or anti-aligned with the motion of the periapse longitudes being identical on average. A large hydrostatic J_2 due to the rapid rotation of Pluto induces large differential precession rates and prevents this condition from being satisfied.

To check that we had overlooked a possible configuration that could allow stable resonant migration for both small satellites, we performed integrations for more than a million sets of initial conditions with massive Nix and Hydra. The large Charon-Pluto mass ratio led to rapid instability in all cases. Apparently it is not possible to transport Nix and Hydra from close orbits to their current positions by their being trapped in mean motions resonances with Charon.

4. Discussion

An alternative explanation for Nix and Hydra is the creation of a dissipative debris disk around Pluto-Charon after the tidal evolution is complete [4]. Such a dissipative disk would settle to the plane of the Pluto-Charon orbit. Could objects in the Nix and Hydra orbits survive the perturbations by Charon? Will they be the only things to survive? The New Horizons spacecraft will detect any additional debris in orbit around Pluto-Charon and its distribution could be consistent with N-body calculations of the disk evolution that are currently under way.

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References

[1] Canup, R.M, A giant impact origin of Pluto-Charon, Science 307, 546-550, 2005.
[2] Weaver, H.A., Stern, S.A., Mutchler, J.J., Seffl, A.J., Buie. M.W., Merline, W.J. Spencer, J.R, Young, E.F. and Young, L.A., Discovery of two new satellites of Pluto, Nature 439, 943-945.
[3] Ward, W.R. and Canup, R.M., Forced resonant migration of Pluto's outer satellites by Charon, Science 313, 1107-1109, 2006.
[4] Lithwick, Y. and Wu, Y., On the origin of Pluto's minor moons, Nix and Hydra, arXiv:0802.2951v1 [astro-ph], 2008.