EPSC Abstracts
Vol. 6, EPSC-DPS2011-178, 2011
EPSC-DPS Joint Meeting 2011

# KCTF Evolution of Trans-Neptunian Binaries

**S. B. Porter** (1,2) and W. M. Grundy (1)
(1) Lowell Observatory, Flagstaff, Arizona, USA, (2) School of Earth and Space Exploration, Arizona State University, USA (porter@lowell.edu)

## Abstract

Recent observational surveys of Trans-Neptunian Binary (TNB) systems have dramatically increased the number of known mutual orbits. Kozai Cycle Tidal Friction (KCTF) simulations of synthetic binary systems shows that tidal dissipation in these systems can totally reshape their orbits. Specifically, solar torques should have dramatically accelerated the tidal decay and circularization of primordial (or recently excited) TNBs. As a result, an initially random distribution of TNBs will evolve to three distinct populations: extremely tight systems, very low inclination systems, and long-term Kozai oscillators. The tight systems account for approximately one third of evolved systems, while one third to one half are coplanar. These populations appear for a range of TNO physical properties, with stronger gravitational quadrapole minimizing variation due to different physical tidal properties.

## 1. Motivation

Trans-Neptunian Binary systems (TNBs) constitute at least 10% of the objects between 30 and 70 AU, and up to 30% of the Cold Classical Kuiper Belt [1]. Mutual orbits have been reported for 24 objects, and separations at discovery for at least 36 more [2, 3]. These observations show that the majority of detected TNB systems have a separation of less than 2% of $a/r_{Hill}$, with most of the systems between 0.3-1.0%. Even more striking is the apparent lack of widely-separated systems, which should be easier to detect, thus implying that TNBs are generally in close mutual orbits. In addition, most known TNBs are almost equal brightness, implying very low mass ratios. Collisional formation would not produce low enough mass ratios, while dynamical captures would produce binaries that are too wide and too eccentric. We therefore use a large set of monte carlo KCTF simulations to show that the currently-observed mutual orbits of TNBs are a function of post-formation evolution, rather than their initial state.

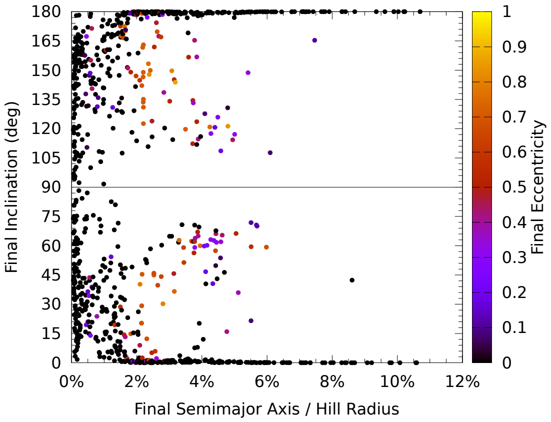

Figure 1: The final post-KCTF orbits for equal-mass TNBs with Q=100 and $J_2$=0.01.

## 2. Simulation Methods

Kozai cycles in this context are the secular oscillations in eccentricity and inclination of the TNB's mutual orbit which preserve the semimajor axis and the quantity $H_k = cos(I) \times \sqrt{1-e^2}$, where $I$ is the inclination of the mutual orbit to the heliocentric orbit. During these oscillations, the eccentricity of the mutual orbit can become very high. Since tidal friction has a much faster drop-off than inverse square ($a^{-8}$ in this model), Kozai-pumped eccentricities can bring the periapse of the orbit sufficiently close that semimajor axis decay and circularization happens much faster than the initial orbit would imply. To simulate this process, we used the KCTF model presented in [4]. This model does not include any dynamical effects external to the TNB system other than the Sun. Each set of KCTF simulations contained 1000 synthetic systems at 44 AU around the Sun and heliocentric $e$ = 0.1. The initial orbits were at random semimajor axes (<12% $r_{Hill}$), eccentricities, and inclinations and each object at random obliquities. The simulations were run for 4.5 Gyr, or until the system reached $e = 10^{-5}$ or impacted each other or separated beyond their mutual Hill radius.

Table 1: The relative populations for equal-mass TNBs; % Tight is number with a $< 1\%$ $r_{Hill}$, % Coplanar is remainder within 5° of coplanarity with the heliocentric orbit.

| Q | $J_2$ | % Tight | % Coplanar | % Other |
|---|---|---|---|---|
| 10 | 0.001 | 43% | 46% | 10% |
| 10 | 0.01 | 38% | 37% | 23% |
| 10 | 0.1 | 31% | 29% | 39% |
| 100 | 0.001 | 39% | 45% | 14% |
| 100 | 0.01 | 33% | 39% | 27% |
| 100 | 0.1 | 31% | 29% | 39% |
| 1000 | 0.001 | 34% | 48% | 17% |
| 1000 | 0.01 | 26% | 45% | 27% |
| 1000 | 0.1 | 31% | 28% | 40% |

## 3. Results

We found that most of the KCTF-evolved TNB systems evolved to either very tight orbits or orbits coplanar with the heliocentric orbit. The orbits that decayed very fast due to KCTF ($< 10^7$ years) stabilized to circular orbits at less than 1% of $r_{Hill}$. Slower-circularizing TNBs stabilized to wider orbits nearly coplanar to the heliocentric orbit. The remainder were in orbits that had a low enough initial $H_k$ that they never reached high enough eccentricity to experience KCTF decay. The relative fraction of these three populations is given in Table 1.

Much of the tightly-bound population is beyond current detection methods. Once methods improve, there should be seen a deficit of objects at separations less than 3.5 times the primary's radius, as the simulations rarely produced orbits closer than this. The vast majority of the coplanar population result from low initial eccentricities ($e < 0.5$), and do extend into observable separations. Since wide, coplanar orbits have not been observed [2, 3], this may imply that TNBs formed in initially eccentric orbits. Alternatively, these orbits could have been perturbed by impacts or close encounters, causing them to decay into much tighter configurations. In addition, the resulting systems preserve their initial prograde/retrograde preference, allowing a tracer of their formation method.

In general, the effect of varying tidal Q was to change the relative fraction of tight and non-decayed systems, with low Q increasing the number tight systems. The effect of adding a significant gravitation $J_2$ was to normalize the tidal properties of the binary systems; at $J_2$=0.1, varying Q two orders of magnitude had almost no effect. Since the giant planet irregular satellites of similar size and density to TNBs generally have a $J_2$ between 0.01 and 0.2, the distribution of actual TNB orbits may be mostly independent of their physical properties. Strong $J_2$ also accelerates the decay of tight systems, while retarding the decay of coplanar systems.

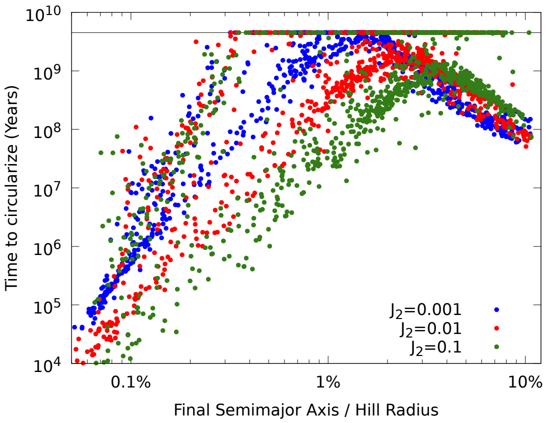

Figure 2: The circularization timescale as a function of final semimajor axis and $J_2$ for equal-mass TNBs with Q=100.

## 4. Conclusions

1. KCTF can significantly transform the orbits of trans-neptunian binaries.
2. A third of random equal-mass TNB systems decay to less than 1% of their mutual Hill radius.
3. A further third-to-half decay to wider orbits within 5° of heliocentric orbit.
4. All resulting systems preserve their initial prograde/retrograde preference.
5. Large $J_2$ moments minimize the effects of varying tidal Q.

## References

[1] D. C. Stephens and K. S. Noll. Detection of Six Trans-Neptunian Binaries with NICMOS: A High Fraction of Binaries in the Cold Classical Disk. AJ, 131:1142–1148, February 2006.

[2] K. S. Noll, W. M. Grundy, E. I. Chiang, J.-L. Margot, and S. D. Kern. *Binaries in the Kuiper Belt*, pages 345–363. 2008.

[3] W. M. Grundy, K. S. Noll, M. W. Buie, S. D. Benecchi, D. C. Stephens, and H. F. Levison. Mutual orbits and masses of six transneptunian binaries. Icarus, 200:627–635, April 2009.

[4] P. P. Eggleton and L. Kiseleva-Eggleton. Orbital Evolution in Binary and Triple Stars, with an Application to SS Lacertae. ApJ, 562:1012–1030, December 2001.