EPSC Abstracts
Vol. 6, EPSC-DPS2011-1350, 2011
EPSC-DPS Joint Meeting 2011

Mutual Inclinations of Ultra-Wide Trans-Neptunian Binaries

A. Parker (1,2), JJ. Kavelaars (3), J.-M. Petit (4), L. Jones (5), B. Gladman (6), J. Parker (7).
(1) University of Victoria Department of Astronomy, BC, Canada, (2) Harvard-Smithsonian Center for Astrophysics, MA, USA, (3) Herzberg Institute of Astrophysics, National Research Council of Canada, BC, Canada, (4) Observatoire de Besançon, France, (5) University of Washington Department of Astronomy, WA, USA, (6) University of British Columbia Department of Astronomy, BC, Canada, (7) Southwest Research Institute, CO, USA.

Abstract

After compiling observations stretching over the last decade, we have determined accurate and precise mutual orbit solutions for all known Ultra-Wide Trans-Neptunian Binaries (TNBs). For all seven binaries in our sample, we have broken the mirror degeneracy in the pole solution, and therefore have non-ambiguous measurements of mutual inclination. These inclinations rule out several binary formation scenarios, and point to formation in a dynamically-cold disk. We present the inclination distribution of ultra-wide TNBs, simulations of collisional evolution of the inclination distribution, and implications for the state of the early Kuiper Belt during the era of binary formation.

1. Introduction

Binary mutual orbits are sensitive tracers of the conditions in the primordial Kuiper Belt and its subsequent history. We selected seven ultra-wide TNB systems for characterization by a ground-based astrometric survey, given the following discovery constraints: (1) no well-characterized orbit in literature, (2) separation at discovery > 0.5", and (3) magnitude difference between system primary and secondary < 1.7 (indicates mass ratio < 10). Complete orbital and physical characterization is presented in a separate paper (Parker et al., submitted). In this work we present the measurement of the mutual inclination distribution of these wide TNBs and its implications.

2. Mutual Inclinations

All pole solutions are non-degenerate at greater than 95% significance. Four systems are found to be prograde and the remaining three are retrograde. The prograde-to-retrograde ratio and its 95% Poisson counting uncertainty for the ultra-wide TNBs is therefore $\sim 1.33^{+4.55}_{-1.02}$.

[1] show that the L_2s will produce a prograde-to-retrograde ratio of approximately 0.03. The current wide binary pole distribution is strongly inconsistent with this prediction, and to be consistent at the 95% level we would require that more than 22% of TNBs have suffered a change of orientation over their lifetimes.

Mutual inclinations are measured between $11.7°$ to $54.6°$. The fact that no system has inclination equal or higher than $\sim 60°$ shows that these inclinations are inconsistent with being drawn from a uniform distribution $P(i) \propto \sin(i)$, since with this distribution half of the systems would have i greater than $60°$. Thus, drawing seven systems and seeing none higher than this has the same probability as getting flipping seven coins and finding all heads-up, $P \sim 0.5^7 \sim 0.008$.

Tighter binaries from literature, however, are consistent with being drawn from a uniform distribution, while they are inconsistent with being drawn from the same distribution as the ultra-wide TNBs (KS test $P < 0.05$). Thus, the wide binaries appear to have a distinct mutual inclination distribution from other TNBs.

3. Evolutionary effects

Via some cursory tests, we find that Kozai Cycles coupled with Tidal Friction (KCTF, eg., [2]) is not sufficient to produce the observed mutual inclination distribution if the primordial inclination distribution was uniform. Additionally, collisional evolution will generally drive a primordially non-uniform inclination distribution *toward* a more uniform distribution, and when *starting* from a uniform mutual inclination, collisions will not drive the overall inclination distribution away from that initial distribution. Thus, neither KCTF nor collisions can produce the current inclination distribution out of a primordially-uniform distri-

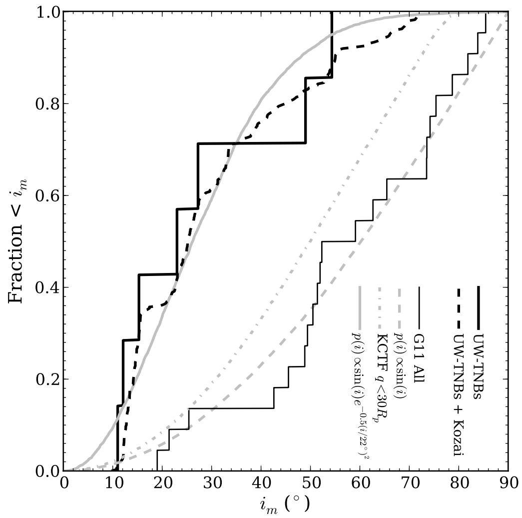

Figure 1: Cumulative mutual inclination distribution of UW TNBs (heavy black histogram) and TNBs from literature (data from [8], light black histogram). Dashed black line shows ultra-wide binaries' inclinations when smoothed over entire Kozai cycle of each object. Gray dashed line: $P(i) \propto sin(i)$. Grey dash-dotted line: uniform distribution modified by strong KCTF. Gray solid line: $P(i) \propto \sin(i)e^{-0.5(i/22^\circ)^2}$.

bution, and the primordial mutual inclination distribution must have preferred low mutual inclinations more strongly than the present-day distribution.

Through impact simulations, we find that collisional evolution cannot produce a large enough population of binaries with reversed pole orientations to account for the discrepancy between the predictions of [1] for the L_2s mechanism; for an initially uniform inclination distribution only $\sim 11\%$ of the binaries suffered a reorientation — much less than required to account for the observed fraction of prograde to retrograde systems if the initial fraction was ~ 0.03.

4. Conclusions

Since aligned mutual orbits are a predicted outcome of a dynamically-cold formation environment (eg., [3, 1]), it is surprising that the L_2s mechanism did not dominate and produce a binary population with almost exclusively retrograde orientations. Additionally, while the L_3 mechanism may be invoked to produce more equal numbers of prograde and retrograde systems, it tends to dominate only in rather dynamically hot conditions where binary formation is less efficient and wide binaries do not survive. Therefore, there is a fine-tuning problem — the disk must be dynamically cold enough for the binary poles to remain aligned with low mutual inclinations and maintain a population of wide binaries, yet be hot enough to prevent the L_2s mechanism from dominating and producing entirely retrograde systems. It is not clear if these two constraints can be met simultaneously with these two processes (L_2s and L_3) alone.

A possible solution is to posit that the binaries in the cold classical Kuiper Belt formed primarily through a third process — direct gravitational collapse (eg., [4]). At present, simulations of this process make no predictions about the inclination distribution they would produce, but the predicted separations and eccentricities well reproduce the observed population of cold classical TNBs (Parker et al. submitted). This mechanism has the advantage that it could occur *in situ* (eg., [5]) without requiring large removal of mass through collisional grinding (destructive to binaries, [6]) or dynamical stripping — eg., no transport by Neptune is required, which is highly destructive to these wide binaries ([7]). Further simulations are merited to determine the predicted inclination distribution produced by this process, as well as the expected ratio of prograde to retrograde systems.

References

[1] Schlichting, H., & Sari, R. ApJ Vol. 686, pp. 741. 2008.

[2] Fabrycky, D. & Tremaine, S. ApJ Vol. 669, pp. 1298. 2007.

[3] Noll, K. Grundy, W., Chiang, E., Margot, J.-L., Kern, S. The Solar System Beyond Neptune. Univ. of Arizona Press, Tucson, AZ. 2008.

[4] Nesvorný, D., Youdin, A. & Richardson, D. AJ Vol. 140, pp. 785. 2010.

[5] Cuzzi, J. Hogan, R., Bottke, W. Icarus Vol. 208, pp. 518. 2010.

[6] Nesvorný, D., Vokrouhlický, D., Bottke, W., Noll, K., Levison, H. AJ Vol. 141, pp. 159. 2011.

[7] Parker, A. H. & Kavelaars, J. J., ApJL Vol. 722, pp. L204. 2010.

[8] Grundy, W. M., Noll, K. S., Nimmo, F., Roe, H. G., Buie, M. W., Porter, S. B., Benecchi, S. D., Stephens, D. C., Levison, H. F. & Stansberry, J. A. Icarus (In press). 2011.