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Five new and three improved mutual orbits of transneptunian binaries

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ABSTRACT

We present three improved and five new mutual orbits of transneptunian binary systems (58534) Logos-Zoe, (66652) Borasisi-Pabu, (88611) Teharonhiawako-Sawiskera, (123509) 2000 WK_{183}, (149780) Altjira, 2001 QY_{297}, 2003 QW_{111}, and 2003 QY_{90} based on Hubble Space Telescope and Keck II laser guide star adaptive optics observations. Combining the five new orbit solutions with 17 previously known orbits yields a sample of 22 mutual orbits for which the period *P*, semimajor axis *a*, and eccentricity *e* have been determined. These orbits have mutual periods ranging from 5 to over 800 days, semimajor axes ranging from 1600 to 37,000 km, eccentricities ranging from 0 to 0.8, and system masses ranging from 2×10^{17} to 2×10^{22} kg. Based on the relative brightnesses of primaries and secondaries, most of these systems consist of near equal-sized pairs, although a few of the most massive systems are more lopsided. The observed distribution of orbital properties suggests that the most loosely-bound transneptunian binary systems are only found on dynamically cold heliocentric orbits. Of the 22 known binary mutual orbits, orientation ambiguities are now resolved for 9, of which 7 are prograde and 2 are retrograde, consistent with a random distribution of orbital orientations, but not with models predicting a strong preference for retrograde orbits. To the extent that other perturbations are not dominant, the binary systems undergo Kozai oscillations of their eccentricities and inclinations with periods of the order of tens of thousands to millions of years, some with strikingly high amplitudes.

1. Introduction

Transneptunian objects (TNOs) record valuable information about the chemical and physical conditions in the outer parts of the protoplanetary nebula where they formed. Since spacecraft access to study their compositions and interior structures is severely limited by their extreme distances, telescopic observations are the only way to study a large sample of TNOs. Their great distances and small sizes limit what can be done using even the most capable telescope facilities. Fortunately, the existence of numerous transneptunian binaries (TNBs) provides a way of learning about their bulk properties via remote observations (e.g., Noll et al., 2008a). They also enable comparisons between TNBs belonging to the various dynamical sub-classes (e.g., Elliot et al., 2005; Gladman et al., 2008). These include "Classical" objects on low inclination, low eccentricity orbits, "Scattered" objects occupying more excited orbits, and "Resonant" objects trapped in a variety of mean motion resonances with Neptune.

The sample of TNBs with known mutual orbits has expanded rapidly in recent years (see Table 1). Remote observation of their mutual orbital semimajor axes and periods gives their total system masses, along with many other properties that would be otherwise unobtainable. The orbits of a large ensemble of binary systems can be used to place additional constraints on possible formation mechanisms as well as subsequent dynamical history. This paper adds five more systems to that sample and improves the orbits of three others.

2. New and improved orbits

Data used in this paper to determine or improve TNB orbits were acquired using the Hubble Space Telescope (HST) and the Keck II telescope on Mauna Kea. Relevant HST observations were

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Table 1
Heliocentric orbital characteristics of TNBs with known orbits.

TNB system		Mean heliocentric orbital elements[a]			Dynamical class[b]
Number,designation, and name		$a_\odot$ (AU)	$e_\odot$	$i_\odot$ (°)	
Systems with new orbits					
(123509)	2000 WK_{183}	44.4	0.048	2.72	Classical
(148780)	2001 UQ_{18} Altjira	44.3	0.059	5.47	Classical
	2001 QY_{297}	43.9	0.074	0.96	Classical
	2003 QW_{111}	43.7	0.109	1.27	Resonant 7:4
	2003 QY_{90}	42.8	0.057	2.21	Classical
Systems with improved orbits					
(58534)	1997 CQ_{29} Logos	45.2	0.125	2.01	Classical
(66652)	1999 RZ_{253} Borasisi	43.8	0.080	1.57	Classical
(88611)	2001 QT_{297} Teharonhiawako	44.1	0.027	4.18	Classical
Systems with published orbits[c]					
(26308)	1998 SM_{165}	47.8	0.375	13.08	Resonant 2:1
(42355)	2002 CR_{46} Typhon	38.1	0.538	3.79	Centaur
(65489)	2003 FX_{128} Ceto	105.4	0.831	21.44	Centaur
(90482)	2004 DW Orcus	39.5	0.254	21.19	Resonant 3:2
(120347)	2004 SB_{60} Salacia	42.1	0.104	25.57	Extended scattered
(134860)	2000 OJ_{67}	42.9	0.013	1.32	Classical
(136199)	2003 UB_{313} Eris	67.9	0.446	43.22	Extended scattered
	1998 WW_{31}	44.7	0.085	8.34	Classical
	1999 OJ4	38.1	0.018	2.58	Classical
	2000 QL_{251}	47.8	0.208	5.80	Resonant 2:1
	2001 QC_{298}	46.3	0.128	31.54	Extended scattered
	2001 XR_{254}	43.0	0.024	2.66	Classical
	2003 TJ_{58}	44.5	0.094	1.31	Classical
	2004 PB_{108}	45.1	0.107	19.19	Extended scattered

[a] Averaged over a 10 Myr integration, with $i_\odot$ relative to the invariable plane as described by Elliot et al. (2005).
[b] Classifications are according to the current Deep Ecliptic Survey system (DES; see links from http://www.boulder.swri.edu/~buie/kbo/desclass.html; the original DES classification scheme was described by Elliot et al. (2005) and a manuscript detailing minor subsequent revisions is in preparation). The Gladman et al. (2008) system would classify these objects much the same, except for Salacia and 2001 QC_{298} which are considered Classical in that system and Eris, which would be classed as detached.
[c] Orbits for these systems have been reported by Veillet et al. (2002), Noll et al. (2004a,b), Brown and Schaller (2007), Grundy et al. (2007, 2008, 2009), Brown et al. (2010), and Stansberry et al. (submitted for publication).

obtained through programs 9060, 9386, 9585, 9746, 9991, 10508, 10514, 10800, and 11178, extending over Cycles 10–16. These nine programs, led by several different investigators, employed a variety of instruments, filters, and observing strategies. Details of astrometric data reduction procedures for various HST programs and instruments are described elsewhere (Stephens and Noll, 2006; Grundy et al., 2008, 2009). In general, relative astrometry was obtained by fitting a pair of Tiny Tim (e.g., Krist and Hook, 2004) point-spread functions (PSFs) to each image, then estimating astrometric uncertainties from the scatter of the separate measurements obtained over the course of each HST visit to a particular system. An uncertainty floor was imposed to avoid over-weighting visits which could happen to have had small measurement scatters by chance. We set this floor to 1 mas for WFPC2/PC data and 0.5 mas for ACS/HRC data. The various filters, cameras, and integration times used in the nine HST programs resulted in a very heterogeneous photometric data set. For filters near V band (*F475W*, *F555W*, and *F606W*) where color information was also available, we converted the observed fluxes to V magnitudes, as described in detail by Benecchi et al. (2009).

Additional observations were done at Keck II using the NIRC2 camera with laser guide star adaptive optics (e.g., Le Mignant et al., 2006). These observations required the presence of a nearby (<30 arcsec) and much brighter (R < 18 mag) appulse star for tip-tilt corrections. Target motion with respect to the appulse star was compensated for by use of a new differential tracking mode implemented by A. Conrad at Keck Observatory. The observations were done in an H band filter (1.49–1.78 μm), using stacks of three consecutive one to two minute integrations followed by a dither, then three more consecutive integrations, and so on. The idea behind recording groups of three frames was to enable us to co-add to reach better sensitivity, while preserving the ability to discard any frames happening to have poor image quality due to variable seeing conditions (which turned out to be a rare occurrence). As with the HST data, astrometric reduction of each stack of three frames was done by means of PSF fitting. We experimented with azimuthally symmetric Gaussian and Lorentzian profiles, and for each visit, selected the profile leading to the lowest χ^2 for the PSF-fit. Most often, this was the Gaussian profile. Its width was fitted simultaneously with the positions of the two components of the binary. We assumed a mean plate scale of 9.963 mas/pixel and an orientation offset of 0.13° (e.g., Ghez et al., 2008; Konopacky et al., 2010). No photometric standards were observed, and no effort was made to compute H band magnitudes from these data, which were taken solely for astrometric purposes.

Table 2 lists the mean relative astrometric measurements and estimated 1-σ uncertainties for the eight systems whose new or improved orbits are presented in this paper. Data from previously published observations are included in the form used in our orbit fits. Observations available in the HST archive were re-reduced using our current pipeline, in order to be as consistent as possible, so the numbers in this table may not exactly agree with previously published numbers from the same data. We also include separate visual photometry for primary and secondary bodies, when available. Visual brightness differences between primaries and secondaries are mostly less than a magnitude, indicative of pairs of similar-sized bodies, but a few systems show magnitude differences greater than two.

For each system, Keplerian orbits were fitted to the astrometric data and uncertainties using nonlinear least squares minimization procedures described by Grundy et al. (2009). Astrometric errors were assumed to obey Gaussian distributions. Where possible, optimal scheduling techniques (Grundy et al., 2008) were used to time subsequent observations so as to minimize the number required to obtain a definitive orbit solution. It is worth describing here what we mean by a definitive TNB orbit solution. Our