Issue No. 68 *March 2010*

DISTANT EKOs

The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

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CONTENTS

NEWS & ANNOUNCEMENTS

There were 30 new TNO discoveries announced since the previous issue of *Distant EKOs*:

2010 AH2, 2009 MA10, 2004 KZ18, 2004 VU130, 2004 VV130, 2005 JA186, 2005 JB186, 2005 JY185, 2005 JZ185, 2005 YL292, 2005 YM292, 2006 CH69, 2006 CJ69, 2006 CK69, 2006 JW81, 2006 OC22, 2006 TM130, 2007 CQ79, 2007 CR79, 2007 CS79, 2007 CT79, 2007 CU79, 2007 CV79, 2007 CW79, 2007 CX79, 2007 RL314, 2007 RM314, 2007 RN314, 2007 RO314, 2007 RP314

and 3 new Centaur/SDO discoveries:

2009 YG19, 2004 VT130, 2010 BL4

Objects recently assigned numbers:
2007 UK126 = (229762)
2004 XA192 = (230965)

Current number of TNOs: 1130 (including Pluto)
Current number of Centaurs/SDOs: 256
Current number of Neptune Trojans: 6

Out of a total of 1392 objects:
584 have measurements from only one opposition
568 of those have had no measurements for more than a year
319 of those have arcs shorter than 10 days
(for more details, see: `http://www.boulder.swri.edu/ekonews/objects/recov_stats.jpg`)

PAPERS ACCEPTED TO JOURNALS

The Colors of Extreme Outer Solar System Objects

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Thirty-three objects with possible origins beyond the Kuiper Belt edge, very high inclinations, very large semi-major axes or large perihelion distances were observed to determine their surface colors. All three objects that have been dynamically linked to the inner Oort cloud (Sedna, 2006 SQ372, and 2000 OO67) were found to have ultra-red surfaces ($S \sim 25$). Ultra-red material is generally associated with rich organics and the low inclination "cold" classical Kuiper Belt objects. The observations detailed here show very red material may be a more general feature for objects kept far from the Sun. The recently discovered retrograde outer Solar System objects (2008 KV42 and 2008 YB3) and the high inclination object (127546) 2002 XU93 show only moderately red surfaces ($S \sim 9$), very similar to known comets. The extended or detached disk objects, which have large perihelion distances and large eccentricities, are found to have mostly moderately red colors ($10 < S < 18$). The colors of the detached disk objects, including the dynamically unusual 2004 XR190 and 2000 CR105, are similar to the scattered disk and Plutino populations. Thus the detached and scattered disk likely have a similar mix of objects from the same source regions. Outer classical belt objects, including 1995 TL8, were found to have very red surfaces ($18 < S < 30$). The "cold" classical belt, outer classical belt and inner Oort cloud appear to be dominated by ultra-red objects ($S > 25$) and thus don't likely have a similar mix of objects as the scattered disk, detached disk and Trojan populations. A possible trend was found for the detached disk and outer classical belt in that objects with smaller eccentricities have redder surfaces irrespective of inclinations or perihelion distances. There is also a clear trend that objects more distant appear redder.

To appear in: The Astronomical Journal (2010 April)

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or on the web at `http://arxiv.org/abs/1001.3674`

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Formation and Dynamical Evolution of the Neptune Trojans – The Influence of the Initial Solar System Architecture

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Current models of Solar system formation suggest that the four giant planets accreted as a significantly more compact system than we observe today. In this work, we investigate the dynamical stability of pre-formed Neptune Trojans under the gravitational influence of the four giant planets in compact planetary architectures, over 10 Myr. In our modelling, the initial orbital locations of Uranus and Neptune (a_N) were varied to produce systems in which those planets moved on non-resonant orbits, or

in which they lay in their mutual 1:2, 2:3 and 3:4 mean-motion resonances (MMRs). In total, 420 simulations were carried out, examining 42 different architectures, with a total of 840000 particles across all runs. In the non-resonant cases, the Trojans suffered only moderate levels of dynamical erosion, with the most compact systems (those with $a_N \leq 18$ AU) losing around 50% of their Trojans by the end of the integrations. In the 2:3 and 3:4 MMR scenarios, however, dynamical erosion was much higher with depletion rates typically greater than 66% and total depletion in the most compact systems. The 1:2 resonant scenarios featured disruption on levels intermediate between the non-resonant cases and other resonant scenarios, with depletion rates of the order of tens of percent. Overall, the great majority of plausible pre-migration planetary architectures resulted in severe levels of depletion of the Neptunian Trojan clouds. In particular, if Uranus and Neptune formed near their mutual 2:3 or 3:4 MMR and at heliocentric distances within 18 AU (as favoured by recent studies), we found that the great majority of pre-formed Trojans would have been lost prior to Neptune's migration. This strengthens the case for the great bulk of the current Neptunian Trojan population having been captured during that migration.

To appear in: Monthly Notices of the Royal Astronomical Society
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2001 QR322: A Dynamically Unstable Neptune Trojan?

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Since early work on the stability of the first Neptunian Trojan, 2001 QR322, suggested that it was a dynamically stable, primordial body, it has been assumed this applies to both that object, and its more recently discovered brethren. However, it seems that things are no longer so clear cut. In this work, we present the results of detailed dynamical simulations of the orbital behaviour of 2001 QR322. Using an ephemeris for the object that has significantly improved since earlier works, we follow the evolution of 19683 test particles, placed on orbits within the observational error ellipse of 2001 QR322's orbit, for a period of 1 Gyr. We find that majority of these 'clones' of 2001 QR322 are dynamically unstable, exhibiting a near-exponential decay from both the Neptunian Trojan cloud (decay halflife $\sim$550 Myr) and the Solar system (decay halflife $\sim$590 Myr). The stability of the object within Neptune's Trojan cloud is found to be strongly dependent on the initial semi-major axis used, with those objects located at $a \geq 30.30$ AU being significantly less stable than those interior to this value, as a result of their having initial libration amplitudes very close to a critical threshold dividing regular and irregular motion, located at 70-75° (full extent of angular motion). This result suggests that, if 2001 QR322 is a primordial Neptunian Trojan, it must be a representative of a population that was once significantly larger than that we see today, and adds weight to the idea that the Neptune Trojans may represent a significant source of objects moving on unstable orbits between the giant planets (the Centaurs).

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Formation of the Extreme Kuiper-belt Binary 2001 QW_{322} Through Adiabatic Switching of Orbital Elements

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Binaries in the Kuiper-belt are unlike all other known binaries in the Solar System. Both their physical and orbital properties are highly unusual and, because these objects are thought to be relics dating back to the earliest days of the Solar System, understanding how they formed may provide valuable insight into the conditions which then prevailed. A number of different mechanisms for the formation of Kuiper-belt binaries (KBBs) have been proposed including; two-body collisions inside the Hill sphere of a larger body; strong dynamical friction; exchange reactions; and chaos assisted capture. So far, no clear consensus has emerged as to which of these mechanisms (if any) can best explain the observed population of KBBs. Indeed, the recent characterization of the mutual orbit of the symmetric (i.e., roughly equal mass) KBB 2001 QW_{322} has only served to complicate the picture because its orbit does not seem readily explicable by any of the available models. The binary 2001 QW_{322} stands out even among the already unusual population of KBBs for the following reasons: its mutual orbit is extremely large ($\approx 10^5$ km or about 30% of the Hill sphere radius), retrograde, it is inclined $\approx 120°$ from the ecliptic and has very low eccentricity, i.e., $e \leq 0.4$ (and possibly $e \leq 0.05$). Here we propose a hybrid formation mechanism for this object which combines aspects of several of the mechanisms already proposed. Initially two objects are temporarily trapped in a long-living chaotic orbit that lies close to a retrograde periodic orbit in the three-dimensional Hill problem. This is followed by capture through gravitational scattering with a small intruder object. Finally, weak dynamical friction gradually switches the original orbit "adiabatically" into a large, almost circular, retrograde orbit similar to that actually observed.

Published in: Celestial Mechanics & Dynamical Astronomy 106, 245 (2010 March)

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Exploring S-type Orbits in the Pluto-Charon Binary System

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This work generates, through a sample of numerical simulations of the restricted three body problem, diagrams of semimajor axis and eccentricity which defines stable and unstable zones for particles in S-type orbits around Pluto and Charon. Since we consider initial conditions with $0 \leq e \leq 0.99$, we found several stable regions not identified in previous studies (Stern *et al.*, 1994; Nagy *et al.*, 2006). We also identified the nature of each one of these newly found stable regions. They are all associated to families of periodic orbits derived from the planar circular restricted three-body problem. We have shown that a possible eccentricity of the Pluto-Charon system (Tholen *et al.*, 2008) slightly reduce, but do not destroy, any of the stable regions.

To appear in: Monthly Notices of the Royal Astronomical Society

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Characterisation of Candidate Members of (136108) Haumea's Family

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Ragozzine & Brown [2007] presented a list of candidate members of the first collisional family to be found among the trans-Neptunian Objects (TNOs), the one associated with (136108) Haumea (2003 EL_{61}). We aim to identify which of the candidate members of the Haumea collisional family are true members, by searching for water ice on their surfaces. We also attempt to test the theory that the family members are made of almost pure water ice by using optical light-curves to constrain their densities. We use optical and near-infrared photometry to identify water ice, in particular using the $(J - H_S)$ colour as a sensitive measure of the absorption feature at 1.6 μm. We use the CH_4 filter of the new Hawk-I instrument at the VLT as a short H-band (H_S) for this as it is more sensitive to the water ice feature than the usual H filter. We report colours for 22 candidate family members, including NIR colours for 15. We confirm that 2003 SQ_{317} and 2005 CB_{79} are family members, bringing the total number of confirmed family members to 10. We reject 8 candidates as having no water ice absorption based on our Hawk-I measurements, and 5 more based on their optical colours. The combination of the large proportion of rejected candidates and time lost to weather prevent us from putting strong constraints on the density of the family members based on the light-curves obtained so far; we can still say that none of the family members (except Haumea) require a large density to explain their light-curve.

Published in: Astronomy & Astrophysics, 511, A72 (2010 February-March)
For preprints, contact `snodgrass@mps.mpg.de`
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Fragmentation Model Dependence of Collision Cascades

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Mass depletion of bodies through successive collisional disruptions (i.e., collision cascade) is one of the most important processes in the studies of the asteroids belt, the Edgeworth-Kuiper belt, debris disks, and planetary formation. The collisional disruption is divided into two types i.e., catastrophic disruption and cratering. Although some studies of the collision cascades neglected the effect of cratering, it is unclear which type of disruption makes a dominant contribution to the collision cascades. In the present study, we construct a simple outcome model describing both catastrophic disruption and cratering, which has some parameters characterizing the total ejecta mass, the mass of the largest fragment, and the power-law exponent of the size distribution of fragments. Using this simple outcome model with parameters, we examine the model dependence of the mass depletion time in collision cascades. We find the cratering collisions are much more effective in collision cascades than collisions with catastrophic disruption in a wide region of the model parameters. It is also found that the mass depletion time in collision cascades is mainly governed by the total ejecta mass and almost insensitive to the mass of the largest fragment and the power-law exponent of fragments for a realistic parameter region. The total ejecta mass is usually determined by the ratio of the impact energy divided by the target mass (i.e. Q-value) to its threshold value $Q^{\star}_{\rm D}$ for catastrophic disruption, as well as in our simple model. We derive a mass depletion time in collision cascades, which is determined by $Q^{\star}_{\rm D}$ of the high-mass end of collision cascades. The mass depletion time derived with our model would be applicable to debris disks and planetary formation.

Published in: Icarus, 206, 735 (2010 April)

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The TAOS Project: Upper Bounds on the Population of Small KBOs and Tests of Models of Formation and Evolution of the Outer Solar System

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We have analyzed the first 3.75 years of data from TAOS, the Taiwanese American Occultation Survey. TAOS monitors bright stars to search for occultations by Kuiper Belt Objects (KBOs). This dataset comprises 5×10^5 star-hours of multi-telescope photometric data taken at 4 or 5 Hz. No events consistent with KBO occultations were found in this dataset. We compute the number of events expected for the Kuiper Belt formation and evolution models of Pan & Sari 2005, Kenyon & Bromley 2004, Benavidez & Campo Bagatin 2009 and Fraser 2010. A comparison with the upper limits we derive from our data constrains the parameter space of these models. This is the first detailed comparison of models of the KBO size distribution with data from an occultation survey. Our results suggest that the KBO population is comprised of objects with low internal strength and that planetary migration played a role in the shaping of the size distribution.

Published in: The Astronomical Journal, 139, 1499 (2010 April)
For preprints, contact `fbianco@lcogt.net`
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Prograde Rotation of Protoplanets by Accretion of Pebbles in a Gaseous Environment

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We perform hydrodynamical simulations of the accretion of pebbles and rocks onto protoplanets of a few hundred kilometres in radius, including two-way drag force coupling between particles and the protoplanetary disc gas. Particle streams interacting with the gas far out within the Hill sphere of the protoplanet spiral into a prograde circumplanetary disc. Material is accreted onto the protoplanet due to stirring by the turbulent surroundings. We speculate that the trend for prograde rotation among the largest asteroids is primordial and that protoplanets accreted 10%-50% of their mass from pebbles and rocks during the gaseous solar nebula phase. Our model also offers a possible explanation for the

narrow range of spin periods observed among the largest bodies in the asteroid and trans-Neptunian belts, and predicts that 1000 km-scale Kuiper belt objects that have not experienced giant impacts should preferentially spin in the prograde direction.

To appear in: Monthly Notices of the Royal Astronomical Society
For preprints, contact p.lacerda@qub.ac.uk
or on the web at http://arxiv.org/abs/0910.1524

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Near-infrared Laboratory Spectra of H_2O Trapped in N_2, CH_4, and CO: Hints for Trans-Neptunian Objects' Observations

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Recent mid-infrared spectroscopic observations of Pluto and Triton suggest a wide distribution of H_2O ice into surface regions containing more volatile species such as N_2, CH_4, and CO. This disagrees with the common idea that because of their typical surface temperature, water should not be involved in volatile transport processes, standing easily segregated from the more volatile species. We analyse infrared H_2O band profiles when water is diluted in solid matrices dominated by methane, carbon monoxide, and/or molecular nitrogen. We also show the results of temperature-related diffusion processes of solid N_2 into H_2O ice deposited at different temperatures. Finally, we analyse ion irradiation effects for some of the mixtures considered. Solid samples were analysed by infrared (1.0-16.0 μm) transmission and reflectance spectroscopy at different temperatures (15-150 K), before and after ion irradiation with 200 keV protons. When water is highly diluted in solid matrices, the profile of its near-infrared bands is strongly modified. Two narrow bands appear around 1.89 μm and 1.39 μm instead of the well known pure water ice bands at 2 μm and 1.5 μm, respectively. Furthermore, the peak position and width of the 1.89 and 1.39 μm bands depend on the initial mixture water is embedded in. The intensity of these bands decreases after ion irradiation. Since the mixtures considered closely resemble the surface composition of trans-Neptunian objects, experiments here discussed show that the bands around 1.89 μm and 1.39 μm are appropriate to investigating the presence of diluted water regions on their surface. In fact, the irradiation dose required for a significant decrease in their intensity would be accumulated on a timescale larger than the timescale for resurfacing processes on the surfaces of trans-Neptunian objects. Results shown here will contribute in a strong way to the interpretation of New Horizons near-infrared observations.

Published in: Astronomy & Astrophysics, 511, A62 (2010 February-March)
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A Search for Ethane on Pluto and Triton

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We present here a search for solid ethane, C_2H_6, on the surfaces of Pluto and Triton, based on near-infrared spectral observations in the H and K bands (1.4-2.45 μm) using the Very Large Telescope (VLT) and the United Kingdom Infrared Telescope (UKIRT). We model each surface using a radiative transfer model based on Hapke theory (Hapke, 1993) with three basic models: without ethane, with pure ethane, and with ethane diluted in nitrogen. On Pluto we detect weak features near 2.27, 2.405, 2.457, and 2.461 μm that match the strongest features of pure ethane. An additional feature seen at 2.317 μm is shifted to longer wavelengths than ethane by at least 0.002 μm. The strength of the features seen in the models suggests that pure ethane is limited to no more than a few percent of the surface of Pluto. On Triton, features in the H band could potentially be explained by ethane diluted in N_2, however, the lack of corresponding features in the K band makes this unlikely (also noted by Quirico et al. 1999, Icarus 139:159-178). While Cruikshank et al. (DPS meeting abstract, 38, 21.03, 2006) find that the 2.406-μm feature on Triton could not be completely due to ^{13}CO, our models show that it could not be accounted for entirely by ethane either. The multiple origin of this feature complicates constraints on the contribution of ethane for both bodies.

To appear in: Icarus

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Pluto and Charon with the Hubble Space Telescope. I. Monitoring Global Change and Improved Surface Properties from Light Curves

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We present new light-curve measurements of Pluto and Charon taken with the Advanced Camera for Surveys High-resolution Camera on the *Hubble Space Telescope*. The observations were collected from 2002 June to 2003 June at 12 distinct sub-Earth longitudes over a range of solar phase angle 0.36°-174° – a larger range than previously measured. The new measurements of Pluto show that the light-curve amplitude has decreased since the mutual event season in the late 1980s. We also show that the average brightness has increased in the F555W (Johnson V equivalent) passband while the brightness has decreased in the F435W (Johnson B equivalent) passband. These data thus indicate a substantial reddening of the reflected light from Pluto. We find a weighted mean $(B-V) = 0.9540 \pm 0.0010$ that is considerably higher than the long-standing value of $(B-V) = 0.868 \pm 0.003$ most recently measured in 1992-1993. This change in color cannot be explained by the evolving viewing geometry and provides the strongest evidence to date for temporal changes on the surface of Pluto that are expected to be linked to volatile transport processes. We also report on the discovery of a new rotational modulation of Pluto's hemispherical color that ranges from 0.92 to 0.98 with the least red color at the longitude of maximum light and most red at minimum light. The phase coefficient of Pluto is nearly the same as measured in 1992-1993 with a value of $\beta_B = 0.0392 \pm 0.0064$ and $\beta_V = 0.0355 \pm 0.0045$ mag deg^{-1} for the F435W and F555W data, respectively. The Pluto phase curve is still very close to linear but a small but significant nonlinearity is seen in the data. In contrast, the light curve of Charon is essentially the same as in 1992/1993, albeit with much less noise. We confirm that Charon's Pluto-facing hemisphere is 8% brighter than the hemisphere facing away from Pluto. The color of Charon is independent of longitude and has a mean weighted value of $(B - V) = 0.7315 \pm 0.0013$. The phase curve for Charon is now shown to be strongly nonlinear and wavelength dependent. We present results for both Pluto and Charon that better constrain the single-particle scattering parameters from the Hapke scattering theory.

Published in: The Astronomical Journal, 139, 1117 (2010 March)
For preprints, contact `buie@boulder.swri.edu`
or on the web at `http://www.boulder.swri.edu/~buie/biblio/`

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Pluto and Charon with the Hubble Space Telescope. II. Resolving Changes on Pluto's Surface and a Map for Charon

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We present new imaging of the surface of Pluto and Charon obtained during 2002-2003 with the *Hubble Space Telescope* (*HST*) Advanced Camera for Surveys (ACS) instrument. Using these data, we construct two-color albedo maps for the surfaces of both Pluto and Charon. Similar mapping techniques are used to re-process HST/Faint Object Camera (FOC) images taken in 1994. The FOC data provide information in the ultraviolet and blue wavelengths that show a marked trend of UV-bright material toward the sunlit pole. The ACS data are taken at two optical wavelengths and show widespread albedo and color variegation on the surface of Pluto and hint at a latitudinal albedo trend on Charon. The ACS data also provide evidence for a decreasing albedo for Pluto at blue (435 nm) wavelengths, while the green (555 nm) data are consistent with a static surface over the one-year period of data collection. We use the two maps to synthesize a true visual color map of Pluto's surface and investigate trends in color. The mid- to high-latitude region on the sunlit pole is, on average, more neutral in color and generally higher albedo than the rest of the surface. Brighter surfaces also tend to be more neutral in color and show minimal color variations. The darker regions show considerable color diversity arguing that there must be a range of compositional units in the dark regions. Color variations are weak when sorted by longitude. These data are also used to constrain astrometric corrections that enable more accurate orbit fitting, both for the heliocentric orbit of the barycenter and the orbit of Pluto and Charon about their barycenter.

Published in: The Astronomical Journal, 139, 1128 (2010 March)
For preprints, contact `buie@boulder.swri.edu`
or on the web at `http://www.boulder.swri.edu/~buie/biblio/`

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Detectability of Oort Cloud Objects Using Kepler

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The size distribution and total mass of objects in the Oort Cloud have important implications to the theory of planet formation, including the properties of, and the processes taking place in the early solar system. We discuss the potential of space missions, such as Kepler and CoRoT, designed to discover transiting exoplanets, to detect Oort Cloud, Kuiper Belt, and main belt objects by occultations of background stars. Relying on published dynamical estimates of the content of the Oort Cloud, we find that Kepler's main program is expected to detect between 0 and ∼100 occultation events by deca-kilometer-sized Oort Cloud objects. The occultation rate depends on the mass of the Oort Cloud, the distance to its "inner edge," and the size distribution of its objects. In contrast, Kepler is unlikely to find occultations by Kuiper Belt or main belt asteroids, mainly due to the fact that it is observing a high ecliptic latitude field. Occultations by solar system objects will appear as a photometric deviation in a single measurement, implying that the information regarding the timescale and light-curve shape of each event is lost. We present statistical methods that have the potential to verify the authenticity of occultation events by solar system objects, to estimate the distance to the occulting population, and to constrain their size distribution. Our results are useful for planning of future space-based exoplanet searches in a way that will maximize the probability of detecting solar system objects, without hampering the main science goals.

Published in: The Astrophysical Journal Letters, 711, L7 (2010 March 1)

Preprint available on the web at `http://arxiv.org/abs/0912.0948`

PAPERS RECENTLY SUBMITTED TO JOURNALS

The Observed Orbital Properties of Binary Minor Planets

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Submitted to: The Astrophysical Journal

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A Unified Model for Short-period Comets: Implications for the Early Solar System

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Submitted to: Monthly Notices of the Royal Astronomical Society

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THESES

Stability Analysis of Asteroid Orbits for Selected Mean Motion Resonances in the Edgeworth-Kuiper Belt

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This dissertation presents a comprehensive description of the stability of asteroid orbits in the Edgeworth-Kuiper belt taking the 3:5, 4:7 and 1:2 mean motion resonance with Neptune as example. Further emphasis is given to the numerical computability of the Lyapunov time of asteroids.

Starting with a general description of rounding and approximation errors in numerical computations, the growth of these errors within numerical integrations is estimated. These, partly machine-dependent errors influence the calculated trajectory of the asteroid as well as the derived Lyapunov time. Different hardware architectures and integration methods were used to investigate the influence on the computed Lyapunov time. As a measure of this dependency a computability index κ is defined. Furthermore it is shown, that the general structure of phase space is robust against these changes.

Subsequently, several selected mean motion resonances in the Edgeworth-Kuiper belt are investigated using these findings. Basic properties, like the resonance width, are deduced from simple models. To get a realistic description of the stability, a huge number of test particles was numerically integrated together with the planets Jupiter to Neptune. The obtained results are compared to the observed distribution of asteroids in the Edgeworth-Kuiper belt.

Please note: the dissertation is written in german! The main results concerning the computability of asteroidal Lyapunov times can be found here: `http://arxiv.org/abs/0901.4871`.

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Exploring the Weak Limit of Gravity at Solar System Scales

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Precision tracking of multiple spacecraft in the outer Solar System has shown an unmodelled perturbation, consisting of a small, constant, radial acceleration directed towards the Sun. Since its detection, a great deal of work has been devoted to explaining this Pioneer effect, both in terms of spacecraft-generated systematics and external physical causes. Its continuing importance is found in the fact that it has been impossible to explain away the effect through conventional means. This leaves open the possibility, however unlikely, that new physics is represented in the effect. This new physics, in turn, would be connected intimately to gravity with huge implications across astrophysics and beyond.

With this as motivation, this dissertation investigates two areas related to the Pioneer effect. The first goal is to investigate the use of planets, comets, and asteroids to determine the reality of the Pioneer effect through precision astrometry.

Here, we showed that asteroids can be used to evaluate the gravitational field in the outer Solar System. The observations can be conducted with modest allocations of telescope time, and would provide a definitive answer to the question within the next 20 years.

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