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DISTANT EKOs

The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

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CONTENTS

NEWS & ANNOUNCEMENTS

There were 2 new TNO discoveries announced since the previous issue of *Distant EKOs*:

2004 LV31, 2004 LW31

and 9 new Centaur/SDO discoveries:

2010 VW11, 2011 HO60, 2012 DD86, 2011 HP83, 2012 DR30, 2012 DS85, 2012 GN12, 2012 GV1, 2012 FZ78

Reclassified objects:

2010 RE64 (TNO → SDO)
2010 RM45 (TNO → SDO)
2011 GM27 (TNO → SDO)
2012 BX85 (TNO → SDO)

Current number of TNOs: 1247 (including Pluto)
Current number of Centaurs/SDOs: 350
Current number of Neptune Trojans: 8

Out of a total of 1605 objects:
643 have measurements from only one opposition
622 of those have had no measurements for more than a year
318 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

Neptune's Wild Days: Constraints from the Eccentricity Distribution of the Classical Kuiper Belt

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Neptune's dynamical history shaped the current orbits of Kuiper belt objects (KBOs), leaving clues to the planet's orbital evolution. In the "classical" region, a population of dynamically "hot" high-inclination KBOs overlies a flat "cold" population with distinct physical properties. Simulations of qualitatively different histories for Neptune – including smooth migration on a circular orbit or scattering by other planets to a high eccentricity – have not simultaneously produced both populations. We explore a general Kuiper belt assembly model that forms hot classical KBOs interior to Neptune and delivers them to the classical region, where the cold population forms in situ. First, we present evidence that the cold population is confined to eccentricities well below the limit dictated by long-term survival. Therefore Neptune must deliver hot KBOs into the long-term survival region without excessively exciting the eccentricities of the cold population. Imposing this constraint, we explore the parameter space of Neptune's eccentricity and eccentricity damping, migration, and apsidal precession. We rule out much of parameter space, except where Neptune is scattered to a moderately eccentric orbit ($e > 0.15$) and subsequently migrates a distance $\Delta a_N = 1$–6 AU. Neptune's moderate eccentricity must either damp quickly or be accompanied by fast apsidal precession. We find that Neptune's high eccentricity alone does not generate a chaotic sea in the classical region. Chaos can result from Neptune's interactions with Uranus, exciting the cold KBOs and placing additional constraints. Finally, we discuss how to interpret our constraints in the context of the full, complex dynamical history of the solar system.

To appear in: The Astrophysical Journal

For preprints, contact `rdawson@cfa.harvard.edu`

or on the web at `http://arxiv.org/abs/1202.6060`

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2008 LC18: A Potentially Unstable Neptune Trojan

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The recent discovery of the first Neptune Trojan at the planet's trailing (L5) Lagrange point, 2008 LC18, offers an opportunity to confirm the formation mechanism of a member of this important tracer population for the Solar System's dynamical history. We tested the stability of 2008 LC18's orbit through a detailed dynamical study, using test particles spread across the $\pm 3\sigma$ range of orbital uncertainties in a, e, i and Ω. This showed that the wide uncertainties of the published orbit span regions of both extreme dynamical instability, with lifetimes < 100 Myr, and with significant stability (> 1 Gyr lifetimes). The stability of 2008 LC18's clones is greatly dependent on their semi-major axis and only weakly correlated with their orbital eccentricity. Test particles on orbits with an initial semi-major axis of less than 29.91 AU have dynamical half-lives shorter than 100 Myr; in contrast, particles with an initial semi-major axis of greater

than 29.91 AU exhibit such strong dynamical stability that almost all are retained over the 1 Gyr of our simulations. More observations of this object are necessary to improve the orbit. If 2008 LC18 is in the unstable region, then our simulations imply that it is either a temporary Trojan capture, or a representative of a slowly decaying Trojan population (like its sibling the L4 Neptunian Trojan 2001 QR322), and that it may not be primordial. Alternatively, if the orbit falls into the larger, stable region, then 2008 LC18 is a primordial member of the highly stable and highly inclined component of the Neptune Trojan population, joining 2005 TN53 and 2007 VL305. We attempted to recover 2008 LC18 using the 2.3 m telescope at Siding Spring Observatory to provide this astrometry, but were unsuccessful due to the high stellar density of its current sky location near the galactic centre. The recovery of this object will require a telescope in the 8 m class.

To appear in: Monthly Notices of the Royal Astronomical Society
For preprints, contact j.a.horner@unsw.edu.au
or on the web at http://arxiv.org/abs/1202.3279

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The Extra Red Plutino (55638) 2002 VE$_{95}$

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Aims. In the framework of a large program, we observed (55638) 2002 VE$_{95}$ with the ESO-VLT telescope to better constrain its surface composition and to investigate the possible heterogeneity of the surface.

Methods. We report new near-infrared observations performed in 2007 and 2008. Using the new constraints of the albedo obtained by Herschel Space Observatory observations, a surface model was computed using the complete set of spectra (from visible to the near-infrared) as well as those of the previous published data to investigate the surface composition properties of (55638) 2002 VE$_{95}$.

Results. The surface is heterogeneous. This red object is covered by different icy compounds, such as water (4–19%) and methanol (10–12%). Different organic compounds, such as titan and triton tholins seem also to be present in the surface. The amount of the components is different depending on the observed area. That methanol ice seems to be present mainly on very red surface favors the hypothesis that surfaces of very red objects are more primordial.

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Links Between the Dynamical Evolution and the Surface Color of The Centaurs

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The Centaurs are a transitional population of minor bodies of the solar system and the evolutionary link between the trans-Neptunian objects and the short period comets. The surface properties of these objects are very peculiar, because currently available data suggest that their visual surface colors divide the population into two distinctive groups, those with reddish slopes of the visual reflection spectra and those with neutral spectra. Moreover, some of them are known to posses comas produced by cometary activity.

We aim to investigate possible links between the orbital dynamical history and the surface physical properties of the bodies of this population.

By means of numerical integrations of the equations of motion we calculated the orbital evolution of three groups of Centaurs: the *Red* group, the *Gray* group and the *Active* group. We looked for statistical differences in the timescales spent by the objects of each group at heliocentric distances below certain values that are associated with locations where certain particular physical processes occur at the surfaces.

We find remarkable differences when we compare the fraction of objects that penetrate below typical heliocentric distances for each group.

Our results suggest that the observed bimodality in the distribution of surface colors of the Centaurs is caused by the different thermal reprocessing on the surface of bodies of the *Red* group on one side and the *Active* and *Gray* groups on the other. Centaurs of the *Gray* group likely had cometary activity, therefore their color distribution is similar to that of comet nuclei.

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Water Ice in the Kuiper Belt

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We examine a large collection of low resolution near-infrared spectra of Kuiper belt objects and centaurs in an attempt to understand the presence of water ice in the Kuiper belt. We find that water ice on the surface of these objects occurs in three separate manners: (1) Haumea family members uniquely show surfaces of nearly pure water ice, presumably a consequence of the fragmentation of the icy mantle of a larger differentiated proto-Haumea; (2) large objects with absolute magnitudes of $H < 3$ (and a limited number to $H = 4.5$) have surface coverings of water ice – perhaps mixed with ammonia – that appears to be related to possibly ancient cryovolcanism on these large objects; and (3) smaller KBOs and centaurs which are neither Haumea family members nor cold-classical KBOs appear to divide into two families (which we refer to as "neutral" and "red"), each of which is a mixture of a common nearly-neutral component and either a slightly red or very red component that also includes water ice. A model suggesting that the difference between neutral and red objects s due to formation in an early compact solar system either inside or outside, respectively, of the ∼20 AU methanol evaporation line is supported by the observation

that methanol is only detected on the reddest objects, which are those which would be expected to have the most of the methanol containing mixture.

To appear in: The Astronomical Journal
For preprints, contact mbrown@caltech.edu
or on the web at http://arxiv.org/abs/1204.3638

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Ice Mineralogy Across and Into the Surfaces of Pluto, Triton, and Eris

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We present three near-infrared spectra of Pluto taken with the IRTF and SpeX, an optical spectrum of Triton taken with the MMT and the Red Channel Spectrograph, and previously published spectra of Pluto, Triton, and Eris. We combine these observations with a two-phase Hapke model, and gain insight into the ice mineralogy on Pluto, Triton, and Eris. Specifically, we measure the methane-nitrogen mixing ratio across and into the surfaces of these icy dwarf planets. In addition, we present a laboratory experiment that demonstrates it is essential to model methane bands in spectra of icy dwarf planets with two methane phases – one highly-diluted by nitrogen and the other rich in methane.

For Pluto, we find bulk, hemisphere-averaged, methane abundances of $9.1 \pm 0.5\%$, $7.1 \pm 0.4\%$, and $8.2 \pm 0.3\%$ for sub-Earth longitudes of 10°, 125°, and 257°. Application of the Wilcoxon rank sum test to our measurements finds these small differences are statistically significant. For Triton, we find bulk, hemisphere-averaged, methane abundances of $5.0 \pm 0.1\%$ and $5.3 \pm 0.4\%$ for sub-Earth longitudes of 138° and 314°. Application of the Wilcoxon rank sum test to our measurements finds the differences are not statistically significant. For Eris, we find a bulk, hemisphere-averaged, methane abundance of $10 \pm 2\%$.

Pluto, Triton, and Eris do not exhibit a trend in methane-nitrogen mixing ratio with depth into their surfaces over the few cm range probed by these observations. This result is contrary to the expectation that since visible light penetrates deeper into a nitrogen-rich surface than the depths from which thermal emission emerges, net radiative heating at depth would drive preferential sublimation of nitrogen leading to an increase in the methane abundance with depth.

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For preprints, contact Stephen.Tegler@nau.edu
or on the web at http://arxiv.org/abs/1203.6888

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"TNOs are Cool": A Survey of the Trans-Neptunian Region VI. *Herschel*/PACS Observations and Thermal Modeling of 19 Classical Kuiper Belt Objects

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Trans-Neptunian objects (TNO) represent the leftovers of the formation of the Solar System. Their physical properties provide constraints to the models of formation and evolution of the various dynamical classes of objects in the outer Solar System.

Based on a sample of 19 classical TNOs we determine radiometric sizes, geometric albedos and beaming parameters. Our sample is composed of both dynamically hot and cold classicals. We study the correlations of diameter and albedo of these two subsamples with each other and with orbital parameters, spectral slopes and colors. We have done three-band photometric observations with *Herschel*/PACS and we use a consistent method for data reduction and aperture photometry of this sample to obtain monochromatic flux densities at 70.0, 100.0 and 160.0 μm. Additionally, we use *Spitzer*/MIPS flux densities at 23.68 and 71.42 μm when available, and we present new *Spitzer* flux densities of eight targets. We derive diameters and albedos with the near-Earth asteroid thermal model (NEATM). As auxiliary data we use reexamined absolute visual magnitudes from the literature and data bases, part of which have been obtained by ground based programs in support of our *Herschel* key program.

We have determined for the first time radiometric sizes and albedos of eight classical TNOs, and refined previous size and albedo estimates or limits of 11 other classicals. The new size estimates of 2002 MS_4 and 120347 Salacia indicate that they are among the 10 largest TNOs known. Our new results confirm the recent findings that there are very diverse albedos among the classical TNOs and that cold classicals possess a high average albedo (0.17 ± 0.04). Diameters of classical TNOs strongly correlate with orbital inclination in our sample. We also determine the bulk densities of six binary TNOs.

To appear in: Astronomy and Astrophysics

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or on the web at `http://arxiv.org/abs/1204.0697`

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"TNOs are Cool": A Survey of the Trans-Neptunian Region – VII. Size and Surface Characteristics of (90377) Sedna and 2010 EK139

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We present estimates of the basic physical properties (size and albedo) of (90377) Sedna, a prominent member of the detached trans-Neptunian object population and the recently discovered scattered disk object 2010 EK139, based on the recent observations acquired with the Herschel Space Observatory, within the "TNOs are Cool!" key programme. Our modeling of the thermal measurements shows that both objects have larger albedos and smaller sizes than the previous expectations, thus their surfaces might be covered by ices in a significantly larger fraction. The derived diameter of Sedna and 2010 EK139 are $995 \pm 80\,\mathrm{km}$ and $470^{+35}_{-10}\,\mathrm{km}$, while the respective geometric albedos are $p_{\rm V} = 0.32 \pm 0.06$ and $0.25^{+0.02}_{-0.05}$. These estimates are based on thermophysical model techniques.

To appear in: Astronomy & Astrophysics Letters
For preprints, contact apal@szofi.net
or on the web at http://arxiv.org/abs/1204.0899

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Dynamical Parameter Determinations in Pluto's System - Expected Constraints from the New Horizons Mission to Pluto

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Pluto is the multiple system that has been observed the longest. Yet, the masses of its smallest satellites, Nix and Hydra, which were discovered in 2005, are still imprecisely known, because of the short time span and number of available observations. We present a numerical model that takes into account the second order gravity fields and Pluto's orbital motion in the solar system. We investigated the dynamical parameters that may be reliably determined today. We also assessed the possible improvements on the parameter uncertainties with the future increase of observations, including the New Horizons mission. Fitting our model to simulated data, we show that the precision of observations prevents the quantification of the polar oblateness J2 and equatorial bulge c22 of Pluto and Charon. Similarly, we show that the masses are on the detection limit. In particular, unless 25 observations are made every year, the mass of Nix may be constrained with confidence only with New Horizons data. Hydra's mass will only be constrained by the probe. The recent discovery of P4 might change this situation, but our knowledge of this object is still too vague to draw any conclusion.

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For preprints, contact `beauvalet@imcce.fr`

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Candidate Stellar Occultations by Large Trans-Neptunian Objects up to 2015

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We study large trans-neptunian objects (TNOs) using stellar occultations. We derive precise astrometric predictions for stellar occultations by Eris, Haumea, Ixion, Makemake, Orcus, Quaoar, Sedna, Varuna, 2002 TX_{300}, and 2003 AZ_{84} for 2011–2015. We construct local astrometric catalogs of stars complete to magnitudes as faint as $R = 18 - 19$ in the UCAC2 (Second US Naval Observatory CCD Astrograph Catalog) frame covering the sky path of these objects. During 2007–2009, we carried out an observational program at the ESO2p2/WFI (2.2 m Max-Planck ESO telescope with the Wide Field Imager) instrument. The observations covered the sky path of the selected targets from 2008 to 2015. We performed the astrometry of 316 GB images using the Platform for Reduction of Astronomical Images Automatically (PRAIA). With the help of field distortion patterns derived for the WFI mosaic of CCDs, we reduced the overlapping mosaics of CCDs. We derive positions in the UCAC2 frame with 40 mas precision for stars up to the catalog magnitude completeness limit (about $R = 19$). New stellar proper motions are also determined with 2MASS (Two Micron All Sky Survey) and the USNO B1.0 (United States Naval Observatory B 1.0) catalog positions as a first epoch. Astrometric catalogs with proper motions were produced for each TNO, containing more than 5.35 million stars covering the sky paths with $30'$ width in declination. The magnitude completeness is about $R = 19$ with a limit of about $R = 21$. We predicted 2717 stellar occultation candidates for all targets. Ephemeris offsets with about from 50 mas to 100 mas precision were applied to each TNO orbit to improve the predictions. They were obtained during 2007–2010 from a parallel observational campaign carried out with from 0.6 m to 2.2 m in size telescopes. This extends our previous work for the Pluto system to large TNOs, using the same observational and astrometric procedures. The obtained astrometric catalogs are useful for follow-up programs at small to large telescopes used to improve the candidate star positions and TNO ephemeris. They also furnish

valuable photometric information for the field stars. For each TNO, updates on the ephemeris offsets and candidate star positions (geometric conditions of predictions and finding charts) are made available in the web by the group: `http://www.lesia.obspm.fr/perso/bruno-sicardy/`

To appear in: Astronomy & Astrophysics
Preprints on the web at `http://arxiv.org/abs/1204.4234`
and `http://www.aanda.org/articles/aa/pdf/forth/aa18349-11.pdf`

OTHER PAPERS OF INTEREST

A Method to Constrain the Size of the Protosolar Nebula

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Observations indicate that the gaseous circumstellar disks around young stars vary significantly in size, ranging from tens to thousands of AU. Models of planet formation depend critically upon the properties of these primordial disks, yet in general it is impossible to connect an existing planetary system with an observed disk. We present a method by which we can constrain the size of our own protosolar nebula using the properties of the small body reservoirs in the solar system. In standard planet formation theory, after Jupiter and Saturn formed they scattered a significant number of remnant planetesimals into highly eccentric orbits. In this paper, we show that if there had been a massive, extended protoplanetary disk at that time, then the disk would have excited Kozai oscillations in some of the scattered objects, driving them into high-inclination ($i \gtrsim 50°$), low-eccentricity orbits ($q \gtrsim 30$ AU). The dissipation of the gaseous disk would strand a subset of objects in these high-inclination orbits; orbits that are stable on Gyr timescales. To date, surveys have not detected any Kuiper-belt objects with orbits consistent with this dynamical mechanism. Using these non-detections by the Deep Ecliptic Survey and the Palomar Distant Solar System Survey we are able to rule out an extended gaseous protoplanetary disk ($R_D \gtrsim 80$ AU) in our solar system at the time of Jupiter's formation. Future deep all sky surveys such as the Large Synoptic Survey Telescope will allow us to further constrain the size of the protoplanetary disk.

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For preprints, contact `kretke@boulder.swri.edu`
or on the web at `http://arxiv.org/abs/1202.2343`

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(1173) Anchises - Thermophysical and Dynamical Studies of a Dynamically Unstable Jovian Trojan

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We have performed detailed thermophysical and dynamical modelling of the Jovian Trojan (1173) Anchises. Our results show that this is a most unusual object. By examining observational data taken of Anchises by IRAS, Akari and WISE at wavelengths between 11.5 and 60 microns, together with the variations in its optical lightcurve, we find that Anchises is most likely an elongated body, with an axes-ratio, a/b, of around 1.4. This results in calculated best-fit dimensions for Anchises of 170x121x121 km (or an equivalent diameter of 136 +18/-11 km). We find that the observations of Anchises are best fit by the object having a retrograde sense of rotation, and an unusually high thermal inertia in the range 25 to 100 $\mathrm{Jm^{-2}s^{-0.5}K^{-1}}$ (3-σ confidence level). The geometric albedo of Anchises is found to be 0.027 (+0.006/-0.007). Anchises therefore has one of the highest published thermal inertias of any object larger than 100 km in diameter, at such large heliocentric distances, as well as being one of the lowest albedo objects ever observed. More observations (visual and thermal) are needed to see whether there is a link between the very shallow phase curve, with almost no opposition effect, and the derived thermal properties for this large Trojan asteroid. Our dynamical investigation of Anchises' orbit has revealed it to be dynamically unstable on timescales of hundreds of millions of years, similar to the unstable Neptunian Trojans 2001 $\mathrm{QR_{322}}$ and 2008 $\mathrm{LC_{18}}$. Unlike those objects, however, we find that the dynamical stability of Anchises is not a function of its initial orbital elements, the result of the exceptional precision with which its orbit is known. Our results are the first time that a Jovian Trojan has been shown to be dynamically unstable, and add further weight to the idea that the planetary Trojans likely represent a significant ongoing contribution to the dynamically unstable Centaur population, the parents of the short-period comets. The observed instability (fully half of all clones of Anchises escape the Solar system within 350 Myr) does not rule out a primordial origin for Anchises, but when taken in concert with the result of our thermophysical analysis, suggest that it would be a fascinating target for future study.

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For preprints, contact `j.a.horner@unsw.edu.au`

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