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DISTANT EKOs

The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

ekonews@boulder.swri.edu www.boulder.swri.edu/ekonews

CONTENTS

NEWS & ANNOUNCEMENTS

There were 7 new TNO discoveries announced since the previous issue of *Distant EKOs*:

2015 RC277, 2015 VA164, 2015 VB164, 2015 VC164, 2015 VD164, 2016 SP55, 2017 OF69

and 4 new Centaur/SDO discoveries:

2015 KE172, 2015 BP519, 2015 KF172, 2015 KG172

Reclassified objects:
2013 JU63 (SDO → TNO)
2016 FX58 (TNO → SDO)

Objects recently assigned numbers:
2012 HZ84 = (516977)
2015 KZ120 = (517717)
2016 FH13 = (518151)

Current number of TNOs: 1934 (including Pluto)
Current number of Centaurs/SDOs: 768
Current number of Neptune Trojans: 17

Out of a total of 2719 objects:
691 have measurements from only one opposition
683 of those have had no measurements for more than a year
341 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

On the Detectability of Planet X with LSST

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Two planetary mass objects in the far outer solar system — collectively referred to here as Planet X — have recently been hypothesized to explain the orbital distribution of distant Kuiper Belt Objects. Neither planet is thought to be exceptionally faint, but the sky locations of these putative planets are poorly constrained. Therefore, a wide area survey is needed to detect these possible planets. The Large Synoptic Survey Telescope (LSST) will carry out an unbiased, large area (around 18,000 deg^2), deep (limiting magnitude of individual frames of 24.5) survey (the "wide-fast-deep (WFD)" survey) of the southern sky beginning in 2022, and it will therefore be an important tool in searching for these hypothesized planets. Here, we explore the effectiveness of LSST as a search platform for these possible planets. Assuming the current baseline cadence (which includes the WFD survey plus additional coverage), we estimate that LSST will confidently detect or rule out the existence of Planet X in 61% of the entire sky. At orbital distances up to ∼75 au, Planet X could simply be found in the normal nightly moving object processing; at larger distances, it will require custom data processing. We also discuss the implications of a nondetection of Planet X in LSST data.

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For preprints, contact `david.trilling@nau.edu`

or on the web at `http://adsabs.harvard.edu/abs/2018AJ....155..243T`

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The Generation of the Distant Kuiper Belt by Planet Nine from an Initially Broad Perihelion Distribution

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The observation that the orbits of long-period Kuiper Belt objects are anomalously clustered in physical space has recently prompted the Planet Nine hypothesis — the proposed existence of a distant and eccentric planetary member of our solar system. Within the framework of this model, a Neptune-like perturber sculpts the orbital distribution of distant Kuiper Belt objects through a complex interplay of resonant and secular effects, such that in addition to perihelion-circulating objects, the surviving orbits get organized into apsidally aligned and anti-aligned configurations with respect to Planet Nine's orbit. In this work, we investigate the role of Kuiper Belt initial conditions on the evolution of the outer solar system using numerical simulations. Intriguingly, we find that the final perihelion distance distribution depends strongly on the primordial state of the system, and demonstrate that a bimodal structure corresponding to the existence of both aligned and anti-aligned clusters is only reproduced if the initial perihelion distribution is assumed to extend well beyond ∼ 36 AU. The bimodality in the final perihelion distance distribution is due to the existence of permanently stable objects, with the lower perihelion peak corresponding to the anti-aligned orbits and the higher perihelion peak corresponding to the aligned orbits. We identify the

mechanisms which enable the persistent stability of these objects and locate the regions of phase space in which they reside. The obtained results contextualize the Planet Nine hypothesis within the broader narrative of solar system formation, and offer further insight into the observational search for Planet Nine.

Published in: The Astronomical Journal, 155, 250 (2018 June)
For preprints, contact talikh@umich.edu
or on the web at http://adsabs.harvard.edu/abs/2018AJ....155..250K

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K2 Precision Lightcurve: Twelve Days in the Pluto-Charon System

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The *Kepler* spacecraft's imaging photometer monitored the Pluto system from October-December 2015 during Campaign 7 of the K2 extended mission. *Kepler* obtained an unprecedented and fortuitous nearly continuous 12-Pluto day lightcurve from measurements acquired every 30 minutes using long cadence sampling. This 3-month-long baseline anchors the Pluto+Charon lightcurve near the time of the *New Horizons* July 2015 encounter, observing at solar phase angles between 1.16° and 1.74°. Long-term modeling of Pluto's lightcurve will ultimately reveal its long-term seasonal variation. K2's combined Pluto+Charon lightcurves measured at this epoch have an average total amplitude of 0.120 ± 0.006, 0.07 magnitudes smaller than the amplitude predicted by a static frost model (Buie & Tholen 1989) projected from *Hubble Space Telescope* surface maps (Buie et al. 1992). Subtracting a static Charon lightcurve from the Pluto+Charon K2 lightcurve produces the same results. Likewise, we subtract each rotation model from the model for the first full rotation and find that the average difference of all variations is 0.017 ± 0.008 magnitudes. Moreover, the difference between the first and last K2 rotation is 0.005 magnitudes, implying that there are no significant changes in the lightcurve during the 3 months of K2 observations. These results are consistent with seasonal transport on Pluto's surface and the predictions of Buratti et al. 2015a. However, a detailed understanding of the surface-atmosphere interactions associated with these phenomena requires decades of monitoring.

To appear in: Icarus, 314, 285 (2018 November)
For preprints, contact susank@psi.edu
or on the web at https://doi.org/10.1016/j.icarus.2018.05.015

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Pluto's Haze as a Surface Material

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Pluto's atmospheric haze settles out rapidly compared with geological timescales. It needs to be accounted for as a surface material, distinct from Pluto's icy bedrock and from the volatile ices that migrate via sublimation and condensation on seasonal timescales. This paper explores how a steady supply of atmospheric haze might affect three distinct provinces on Pluto. We pose the question of why they each look so different from one another if the same haze material is settling out onto all of them. Cthulhu is a more ancient region with comparatively little present-day geological activity, where the haze appears to simply accumulate over time. Sputnik Planitia is a very active region where glacial convection, as well as sublimation and condensation rapidly refresh the surface, hiding recently deposited haze from view. Lowell Regio is a region of intermediate age featuring very distinct coloration from the rest of Pluto. Using a simple model haze particle as a colorant, we are not able to match the colors in both Lowell Regio and Cthulhu. To account for their distinct colors, we propose that after arrival at Pluto's surface, haze particles may be less inert than might be supposed from the low surface temperatures. They must either interact with local materials and environments to produce distinct products in different regions, or else the supply of haze must be non-uniform in time and/or location, such that different products are delivered to different places.

To appear in: Icarus, 314, 232 (2018 November)
Available online at: `http://adsabs.harvard.edu/abs/2018Icar..314..232G`
For preprints, see `http://www2.lowell.edu/~grundy/abstracts/2018.Pluto_haze.html`

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Primordial N_2 Provides a Cosmochemical Explanation for the Existence of Sputnik Planitia, Pluto

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The presence of N_2 in the surface environment of Pluto is critical in creating Pluto's richness of features and processes. Here, we propose that the nitrogen atoms in the N_2 observed on Pluto were accreted in that chemical form during the formation of Pluto. We use New Horizons data and models to estimate the amounts of N_2 in the following exterior reservoirs: atmosphere, escape, photochemistry, and surface. The total exterior inventory is deduced to be dominated by a glacial sheet of N_2-rich ices at Sputnik Planitia, or by atmospheric escape if past rates of escape were much faster than at present. Pluto's atmosphere is a negligible reservoir of N_2, and photochemical destruction of N_2 may also be of little consequence. Estimates are made of the amount of N_2 accreted by Pluto based on cometary and solar compositions. It is found that the cometary model can account for the amount of N_2 in Sputnik Planitia, while the solar model can provide a large initial inventory of N_2 that would make prodigious atmospheric escape possible. These consistencies can be considered preliminary evidence in support of a primordial origin of Pluto's N_2. However, both models predict accreted ratios of CO/N_2 that are much higher than that in Pluto's atmosphere. Possible processes to explain "missing CO" that are given quantitative support here are fractional crystallization from the atmosphere resulting in CO burial at the surface, and aqueous destruction reactions of CO subject to metastable thermodynamic equilibrium in the subsurface. The plausibility of primordial N_2 as the primary source of Pluto's nitrogen (vs. NH_3 or organic N) can be tested more rigorously using future constraints on the $^{14}N/^{15}N$ ratio in N_2 and the $^{36}Ar/N_2$ ratio.

To appear in: Icarus, 313, 79 (2018 October)

For preprints, contact cglein@swri.edu

or on the web at https://arxiv.org/abs/1805.09285

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Resonances in the Asteroid and Trans-Neptunian Belts: A Brief Review

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Mean motion resonances play a fundamental role in the dynamics of the small bodies of the Solar System. The last decades of the 20th century gave us a detailed description of the dynamics as well as the process of capture of small bodies in coplanar or small inclination resonant orbits. More recently, semianalytical or numerical methods allowed us to explore the behavior of resonant motions for arbitrary inclination orbits. The emerging dynamics is very rich, including large orbital changes due to secular effects inside mean motion resonances. The process of capture in highly inclined or retrograde resonant orbits was addressed showing that the capture in retrograde resonances is more efficient than in direct ones. A new terminology appeared in order to characterize the properties of the resonances. Numerical explorations in the transneptunian region showed the relevance and the particular dynamics of the exterior resonances with Neptune which can account for some of the known high perihelion orbits in the scattered disk. Moreover, several asteroids evolving in resonance with planets other than Jupiter or Neptune were found and a large number of asteroids in three-body resonances were identified.

To appear in: Planetary and Space Science, 157, 96 (2018 August)

For preprints, contact gallardo@fisica.edu.uy

or on the web at http://adsabs.harvard.edu/abs/2018P%26SS..157...96G

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OSSOS IX: Two Objects in Neptune's 9:1 Resonance – Implications for Resonance Sticking in the Scattering Population

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We discuss the detection in the Outer Solar System Origins Survey (OSSOS) of two objects in Neptune's distant 9:1 mean motion resonance at semimajor axis $a \approx$ 130 au. Both objects are securely resonant on 10 Myr timescales, with one securely in the 9:1 resonance's leading asymmetric libration island and the other in either the symmetric or trailing asymmetric island. These objects are the largest semimajor axis objects with secure resonant classifications, and their detection in a carefully characterized survey allows for the first robust resonance population estimate beyond 100 au. The detection of these objects implies a 9:1 resonance population of 1.1×10^4 objects with $H_r < 8.66$ ($D \gtrsim 100$ km) on similar orbits (95% confidence range of $\sim 0.4 - 3 \times 10^4$). Integrations over 4 Gyr of an ensemble of clones spanning these objects' orbit fit uncertainties reveal that they both have median resonance occupation timescales of ~ 1 Gyr. These timescales are consistent with the hypothesis that these objects originate in the scattering population but became transiently stuck to Neptune's 9:1 resonance within the last ~ 1 Gyr of solar system evolution. Based on simulations of a model of the current scattering population, we estimate the expected resonance sticking population in the 9:1 resonance to be 1000-4500 objects with $H_r < 8.66$; this is marginally consistent with the OSSOS 9:1 population estimate. We conclude that resonance sticking is a plausible explanation for the observed 9:1 population, but we also discuss the possibility of a primordial 9:1 population, which would have interesting implications for the Kuiper belt's dynamical history.

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or on the web at http://adsabs.harvard.edu/abs/2018AJ....155..260V

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Trans-Neptunian Objects Transiently Stuck in Neptune's Mean Motion Resonances: Numerical Simulations of the Current Population

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A substantial fraction of our solar system's trans-Neptunian objects (TNOs) are in mean motion resonance with Neptune. Many of these objects were likely caught into resonances by planetary migration—either smooth or stochastic—approximately 4 Gyr ago. Some, however, gravitationally scattered off of Neptune and became transiently stuck in more recent events. Here, we use numerical simulations to predict the number of transiently-stuck objects, captured from the current actively scattering population, that occupy 111 resonances at semimajor axes a =30–100 au. Our source population is an observationally constrained model of the currently-scattering TNOs. We predict that, integrated across all resonances at these distances, the current transient sticking population comprises 40% of total transiently-stuck+scattering TNOs, suggesting that these objects should be treated as a single population. We compute the relative distribution of transiently-stuck objects across all p:q resonances with $1/6 \leq q/p < 1$, $p < 40$, and $q < 20$, providing predictions for the population of transient objects with $H_r < 8.66$ in each resonance. We find that the relative populations are approximately proportional to each resonance's libration period and confirm that the importance of transient sticking increases with semimajor axis in the studied range. We calculate the expected distribution of libration amplitudes for stuck objects and demonstrate that observational constraints indicate that both the total number and the amplitude-distribution of 5:2 resonant TNOs are inconsistent with a population dominated by transient sticking from the current scattering disk. The 5:2 resonance hence poses a challenge for leading theories of Kuiper belt sculpting.

To appear in: The Astronomical Journal

Preprints on the web at `https://arxiv.org/abs/1805.08228`

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The Disturbing Function for Asteroids with Arbitrary Inclinations

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The classical disturbing function of the three-body problem widely used in planetary dynamics studies is an expansion of the gravitational interaction of the three-body problem with respect to zero eccentricity and zero inclination. This restricts its validity to nearly coplanar orbits. Motivated by the dynamical study of asteroids, Centaurs and transneptunian objects with arbitrary inclinations, we derive a series expansion of the gravitational interaction with respect to an arbitrary reference inclination that generalises our work on the polar and retrograde disturbing functions. The new disturbing function, like the polar one, may model any resonance as expansion order is unrelated to resonance order. The powers of eccentricity and inclination of the force amplitude of a p:q resonance depend only on the parity of the resonance order $|p - q|$. Disturbing functions with non zero reference inclinations are thus physically different from the classical disturbing function as the former are based on the three-dimensional three-body problem and the latter on the two-dimensional one. We illustrate the use of the new disturbing function by showing that what is known as pure eccentricity resonances are intrinsically dependent on inclination contrary to the

prediction of the classical disturbing function. We determine the inclination dependence of the resonance widths of the 2:1 and 3:1 prograde and retrograde inner resonances with Jupiter as well as those of the asymmetric librations of the 1:2 and 1:3 prograde outer resonances with Neptune.

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on the web at `http://adsabs.harvard.edu/abs/2018MNRAS.474..157N`

OTHER PAPERS OF INTEREST

Phoebe: A Surface Dominated by Water

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The Saturnian irregular satellite, Phoebe, can be broadly described as a water-rich rock. This object, which presumably originated from the same primordial population shared by the dynamically excited Kuiper Belt Objects (KBOs), has received high resolution spectral imaging during the Cassini flyby. We present a new analysis of the Visual Infrared Mapping Spectrometer observations of Phoebe, which critically, includes a geometry correction routine that enables pixel-by-pixel mapping of visible and infrared spectral cubes directly onto the Phoebe shape model, even when an image exhibits significant trailing errors. The result of our re-analysis is a successful match of 46 images, producing spectral maps covering the majority of Phoebe's surface, roughly a 3rd of which is imaged by high resolution observations (< 22 km per pixel resolution). There is no spot on Phoebe's surface that is absent of water absorption. The regions richest in water are clearly associated with the Jason and South Pole impact basins. Phoebe exhibits only three spectral types, and a water-ice concentration that correlates with physical depth and visible albedo. The water-rich and water-poor regions exhibit significantly different crater size frequency distributions, and different large crater morphologies. We propose that Phoebe once had a water-poor surface whose water-ice concentration was enhanced by basin forming impacts which exposed richer subsurface layers. The range of Phoebe's water-ice absorption spans the same range exhibited by dynamically excited KBOs. The common water-ice absorption depths and primordial origins, and the association of Phoebe's water-rich regions with its impact basins, suggests the plausible idea that KBOs also originated with water-poor surfaces that were enhanced through stochastic collisional modification.

To appear in: The Astronomical Journal
For preprints, contact `wes.fraser@qub.ac.uk`
or on the web at `https://arxiv.org/abs/1803.04979`

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An Interstellar Origin for Jupiter's Retrograde Co-orbital Asteroid

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Asteroid (514107) 2015 BZ509 was discovered recently in Jupiter's co-orbital region with a retrograde motion around the Sun. The known chaotic dynamics of the outer Solar System have so far precluded the identification of its origin. Here, we perform a high-resolution statistical search for stable orbits and show that asteroid (514107) 2015 BZ509 has been in its current orbital state since the formation of the Solar System. This result indicates that (514107) 2015 BZ509 was captured from the interstellar medium 4.5 billion years in the past as planet formation models cannot produce such a primordial large-inclination orbit with the planets on nearly-coplanar orbits interacting with a coplanar debris disk that must produce the low-inclination small-body reservoirs of the Solar System such as the asteroid and Kuiper belts. This result also implies that more extrasolar asteroids are currently present in the Solar System on nearly-polar orbits.

Published in: Monthly Notices of the Royal Astronomical Society, 477, L117 (2018 June 11)
on the web at `http://adsabs.harvard.edu/abs/2018MNRAS.477L.117N`

BOOKS

Discovering Pluto - Exploration at the Edge of the Solar System

Dale P. Cruikshank and William Sheehan

University of Arizona Press, 2018. 450 pages
https://uapress.arizona.edu/book/discovering-pluto

Table of Contents:

The *Distant EKOs* Newsletter is dedicated to provide researchers with easy and rapid access to current work regarding the Kuiper belt (observational and theoretical studies), directly related objects (e.g., Pluto, Centaurs), and other areas of study when explicitly applied to the Kuiper belt.

We accept submissions for the following sections:
⋆ Abstracts of papers submitted, in press, or recently published in refereed journals
⋆ Titles of conference presentations
⋆ Thesis abstracts
⋆ Short articles, announcements, or editorials
⋆ Status reports of on-going programs
⋆ Requests for collaboration or observing coordination
⋆ Table of contents/outlines of books
⋆ Announcements for conferences
⋆ Job advertisements
⋆ General news items deemed of interest to the Kuiper belt community

A LaTeX template for submissions is appended to each issue of the newsletter, and is sent out regularly to the e-mail distribution list. Please use that template, and send your submission to:

`ekonews@boulder.swri.edu`

The *Distant EKOs* Newsletter is available on the World Wide Web at:

`http://www.boulder.swri.edu/ekonews`

Recent and back issues of the newsletter are archived there in various formats. The web pages also contain other related information and links.

Distant EKOs is not a refereed publication, but is a tool for furthering communication among people interested in Kuiper belt research. Publication or listing of an article in the newsletter or the web page does not constitute an endorsement of the article's results or imply validity of its contents. When referencing an article, please reference the original source; *Distant EKOs* is not a substitute for peer-reviewed journals.

Moving ... ??

If you move or your e-mail address changes, please send the editor your new address. If the newsletter bounces back from an address for three consecutive issues, the address will be deleted from the mailing list. All address changes, submissions, and other correspondence should be sent to:

`ekonews@boulder.swri.edu`