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DISTANT EKOs

The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

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CONTENTS

NEWS & ANNOUNCEMENTS

Icarus will publish a special issue for papers on the Trans-Neptunian Solar System. The issue is associated with the international conference on the same subject recently held in Coimbra (Pt) from March 26 to 29, 2018. However, papers not associated with talks at the conference are welcome. Papers with original (i.e. not previously published) scientific content are sought, not review papers or summaries of previously published works. The deadline for submission is June 30, 2018 (an update from the previously announced date).

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In support of future missions to the Kuiper belt, a community group called the Pluto and Kuiper belt Exploration Group (PKEG) has been created. They have started a website with resources:
`https://sites.google.com/view/pkeg/home`
and to join the e-mail list contact Kelsi Singer (`ksinger@boulder.swri.edu`).

A few recent PKEG news items:

- A self-organized community white paper in support of future Pluto Follow-On missions is available and open for additional signatories if you would like to add your name in support also e-mail `ksinger@boulder.swri.edu`. The white paper can be downloaded here:
  `http://bit.ly/PFO_WhitePaper`
- A second workshop on Kuiper belt future missions was held at the recent Transneptunian Solar System Meeting in Coimbra, Portugal. Thanks to all those who were able to attend and contribute discussion. The slides on various topics can be found here:
  `https://sites.google.com/view/pkeg/workshops`

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There were 12 new TNO discoveries announced since the previous issue of *Distant EKOs*:
2013 UW18, 2013 UX18, 2014 UM233, 2014 WM517, 2015 FV403, 2015 FW403, 2015 QL14, 2016 PA101, 2017 DM121, 2017 DN121, 2017 FP161, 2017 FQ161

and 21 new Centaur/SDO discoveries:
2014 FD70, 2014 FO69, 2014 UO231, 2014 WL517, 2015 FU403, 2015 KV167, 2015 PZ315, 2015 RK258, 2015 RL258, 2015 TG367, 2015 TH367, 2015 TJ367, 2015 UH87, 2015 VG157, 2016 CD289, 2016 SW50, 2016 TS97, 2017 DO121, 2017 DP121, 2017 FO161, 2018 EZ1

Reclassified objects:
2007 TC434 (TNO $\rightarrow$ SDO)

Objects recently assigned numbers:
2016 AE193 = (514312)

Current number of TNOs: 1927 (including Pluto)
Current number of Centaurs/SDOs: 764
Current number of Neptune Trojans: 17

Out of a total of 2708 objects:
700 have measurements from only one opposition
689 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

Thermal Evolution of Trans-Neptunian Objects, Icy Satellites, and Minor Icy Planets in the Early Solar System

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Numerical simulations are performed to understand the early thermal evolution and planetary scale differentiation of icy bodies with the radii in the range of 100-2500 km. These icy bodies include trans-Neptunian objects, minor icy planets (e.g., Ceres, Pluto); the icy satellites of Jupiter, Saturn, Uranus, and Neptune; and probably the icy-rocky cores of these planets. The decay energy of the radionuclides, ^{2}6Al, ^{6}0Fe, ^{4}0K, ^{2}35U, ^{2}38U, and ^{2}32Th, along with the impact-induced heating during the accretion of icy bodies were taken into account to thermally evolve these planetary bodies. The simulations were performed for a wide range of initial ice and rock (dust) mass fractions of the icy bodies. Three distinct accretion scenarios were used. The sinking of the rock mass fraction in primitive water oceans produced by the substantial melting of ice could lead to planetary scale differentiation with the formation of a rocky core that is surrounded by a water ocean and an icy crust within the initial tens of millions of years of the solar system in case the planetary bodies accreted prior to the substantial decay of ^{2}6Al. However, over the course of billions of years, the heat produced due to ^{4}0K, ^{2}35U, ^{2}38U, and ^{2}32Th could have raised the temperature of the interiors of the icy bodies to the melting point of iron and silicates, thereby leading to the formation of an iron core. Our simulations indicate the presence of an iron core even at the center of icy bodies with radii $\geq$500 km for different ice mass fractions.

Published in: Meteoritics & Planetary Science, 52, 2470 (2017 December)
For preprints, contact `sandeep@pu.ac.in`
or on the web at `http://adsabs.harvard.edu/abs/2017M%26PS...52.2470B`

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On the Early In Situ Formation of Pluto's Small Satellites

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The formation of Pluto's small satellites – Styx, Nix, Kerberos, and Hydra – remains a mystery. Their orbits are nearly circular and are near mean-motion resonances and nearly coplanar with Charon's orbit. One scenario suggests that they all formed close to their current locations from a disk of debris that was ejected from the Charon-forming impact before the tidal evolution of Charon. The validity of this scenario is tested by performing N-body simulations with the small satellites treated as test particles and PlutoCharon evolving tidally from an initial orbit at a few Pluto radii with initial eccentricity $e_C = 0$ or 0.2. After tidal evolution, the free eccentricities $e_{\rm free}$ of the test particles are extracted by applying fast Fourier transformation to the distance between the test particles and the center of mass of the system and compared with the current eccentricities of the four small satellites. The only surviving test particles with $e_{\rm free}$ matching the eccentricities of the current satellites are those not affected by mean-motion resonances during the tidal evolution in a model with Pluto's effective tidal dissipation function $Q = 100$ and an initial $e_C = 0.2$ that is damped down rapidly. However, these test particles do not have any preference to be in or near 4:1, 5:1,

and 6:1 resonances with Charon. An alternative scenario may be needed to explain the formation of Pluto's small satellites.

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Available on the web at http://adsabs.harvard.edu/abs/2018AJ....155..175W

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Implications of the Observed Pluto-Charon Density Contrast

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Observations by the New Horizons spacecraft have determined that Pluto has a larger bulk density than Charon by 153 ± 44 kg m^{-3} (2σ uncertainty). We use a thermal model of Pluto and Charon to determine if this density contrast could be due to porosity variations alone, with Pluto and Charon having the same bulk composition. We find that Charon can preserve a larger porous ice layer than Pluto due to its lower gravity and lower heat flux but that the density contrast can only be explained if the initial ice porosity is $\gtrsim$30%, extends to $\gtrsim$100 km depth and Pluto retains a subsurface ocean today. We also find that other processes such as a modern ocean on Pluto, self-compression, water-rock interactions, and volatile (e.g., CO) loss cannot, even in combination, explain this difference in density. Although an initially high porosity cannot be completely ruled out, we conclude that it is more probable that Pluto and Charon have different bulk compositions. This difference could arise either from forming Charon via a giant impact, or via preferential loss of H_2O on Pluto due to heating during rapid accretion.

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For preprints, contact CThomas1@ucsc.edu
or on the web at http://adsabs.harvard.edu/abs/2018Icar..309..207B

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An Upper Limit on Pluto's Ionosphere from Radio Occultation Measurements with New Horizons

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On 14 July 2015 New Horizons performed a radio occultation (RO) that sounded Pluto's neutral atmosphere and ionosphere. The solar zenith angle was 90.2° (sunset) at entry and 89.8° (sunrise) at exit. We examined the data for evidence of an ionosphere, using the same method of analysis as in a previous

investigation of the neutral atmosphere (Hinson et al., Icarus 290, 96-111, 2017). No ionosphere was detected. The measurements are more accurate at occultation exit, where the 1-sigma sensitivity in integrated electron content (IEC) is 2.3×10^{11} cm^{-2}. The corresponding upper bound on the peak electron density at the terminator is about 1000 cm^{-3}. We constructed a model for the ionosphere and used it to guide the analysis and interpretation of the RO data. Owing to the large abundance of CH_4 at ionospheric heights, the dominant ions are molecular and the electron densities are relatively small. The model predicts a peak IEC of 1.8×10^{11} cm^{-2} for an occultation at the terminator, slightly smaller than the threshold of detection by New Horizons.

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For reprints, contact dhinson@seti.org
or on the web at http://adsabs.harvard.edu/abs/2018Icar..307...17H

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The Nitrogen Cycles on Pluto Over Seasonal and Astronomical Timescales

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Pluto's landscape is shaped by the endless condensation and sublimation cycles of the volatile ices covering its surface. In particular, the Sputnik Planitia ice sheet, which is thought to be the main reservoir of nitrogen ice, displays a large diversity of terrains, with bright and dark plains, small pits and troughs, topographic depressions and evidences of recent and past glacial flows. Outside Sputnik Planitia, New Horizons also revealed numerous nitrogen ice deposits, in the eastern side of Tombaugh Regio and at mid-northern latitudes.

These observations suggest a complex history involving volatile and glacial processes occurring on different timescales. We present numerical simulations of volatile transport on Pluto performed with a model designed to simulate the nitrogen cycle over millions of years, taking into account the changes of obliquity, solar longitude of perihelion and eccentricity as experienced by Pluto. Using this model, we first explore how the volatile and glacial activity of nitrogen within Sputnik Planitia has been impacted by the diurnal, seasonal and astronomical cycles of Pluto. Results show that the obliquity dominates the N_2 cycle and that over one obliquity cycle, the latitudes of Sputnik Planitia between 25°S-30°N are dominated by N_2 condensation, while the northern regions between 30°N-50°N are dominated by N_2 sublimation. We find that a net amount of 1 km of ice has sublimed at the northern edge of Sputnik Planitia during the last 2 millions of years. It must have been compensated by a viscous flow of the thick ice sheet. By comparing these results with the observed geology of Sputnik Planitia, we can relate the formation of the small pits and the brightness of the ice at the center of Sputnik Planitia to the sublimation and condensation of ice occurring at the annual timescale, while the glacial flows at its eastern edge and the erosion of the water ice mountains all around the ice sheet are instead related to the astronomical timescale. We also perform simulations including a glacial flow scheme which shows that the Sputnik Planitia ice sheet is currently at its minimum extent at the northern and southern edges. We also explore the stability of N_2 ice deposits outside the latitudes and longitudes of the Sputnik Planitia basin. Results show that N_2 ice is not stable at the poles but rather in the equatorial regions, in particular in depressions, where thick deposits may persist over tens of millions of years, before being trapped in Sputnik Planitia. Finally, another key result is that the minimum and maximum surface pressures obtained over the simulated millions of years remain in the range of milli-Pascals and Pascals, respectively. This suggests that Pluto never encountered conditions allowing liquid nitrogen to flow directly on its surface. Instead, we suggest that the numerous geomorphological evidences of past liquid flow observed on Pluto's surface are the result of liquid nitrogen that flowed at the base of thick ancient nitrogen glaciers, which have since disappeared.

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For preprints, contact tanguy.bertrand@lmd.jussieu.fr
or on the web at http://adsabs.harvard.edu/abs/2018Icar..309..277B

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Young Surface of Pluto's Sputnik Planitia Caused by Viscous Relaxation

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One of the most prominent features of Pluto observed by the New Horizon mission is the absence of craters on Sputnik Planitia (SP). Vigorous thermal convection could renew the SP surface with sufficient depth at a timescale of ∼500,000 years. Here we present numerical simulations demonstrating that craters can be removed much more quickly across all of SP by viscous relaxation of nitrogen (N_2) ice. The timescale of relaxation is in years if the N_2 layer is 4 km thick and the viscosity is as determined in the lab, and will increase to 10^4 years if the viscosity is 10^4 times larger than the measured value. For such high viscosity, the thermal convection will have a timescale of greater than 10^6 years if it happens at all, so that the relaxation timescale is still more than 2 orders of magnitude shorter. The relaxation timescale decreases with increasing thickness and temperature of the ice layer. The existence of pits on SP can be explained by the surface enhancement of viscosity. Such enhancement does not have significant influence on the relaxation timescale of craters with diameters greater than a few kilometers. Therefore, although convection is required to explain the polygon shapes, it may have a lesser role in the absence of craters on SP. The viscous relaxation mechanism can readily explain the nondetection of both craters and polygon shapes on the southeast SP.

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Available on the web at http://adsabs.harvard.edu/abs/2018ApJ...856L..14W

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Surface Ice and Tholins on the Extreme Centaur 2012 DR_{30}

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2012 DR_{30} is one of the known solar system objects with the largest aphelion distance, exceeding 2200 au, on a high inclination orbit ($i = 78°$). It has been recognized to be either a borderline representative of high inclination, high perihelion distance (HiHq) objects, or even a new class of bodies, similar to HiHq objects for orbit but with an aphelion in the inner Oort Cloud. Here, we present photometry using long-term data from 2000 to 2013 taken by the SDSS sky survey, ESO MPG 2.2 m and McDonald 2.1 m telescopes, and a visual+near-infrared spectrum taken with the Southern Astrophysical Research Telescope and Magellan telescopes, providing insights into the surface composition of this body. Our best fit suggests that the surface contains 60% of complex organics (30% of Titan and 30% of Triton tholins) with a significant fraction of ice (30%, including pure water and water with inclusions of complex organics) and 10% silicates. The models also suggest a low limit of amorphous carbons, and hence the fragmentation of long-chained complex organics is slower than their rate of generation. 2012 DR_{30} just recently passed the perihelion, and the long-term photometry of the object suggested ambiguous signs of activity, since the long-term photometric scatter well exceeded the supposed measurement errors and the expected brightness variation related to rotation. Photometric colors put 2012 DR_{30} exactly between dark neutral and red objects, thus it either can be in a transition phase between the two classes or have differing surface properties from these populated classes.

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or on the web at `http://adsabs.harvard.edu/abs/2018AJ....155..170S`

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Visible Near-infrared Spectral Evolution of Irradiated Mixed Ices and Application to Kuiper Belt Objects and Jupiter Trojans

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Understanding the history of Kuiper Belt Objects and Jupiter Trojans will help to constrain models of solar system formation and dynamical evolution. Laboratory simulations of a possible thermal and irradiation history of these bodies were conducted on ice mixtures while monitoring their spectral properties.

These simulations tested the hypothesis that the presence or absence of sulfur explains the two distinct visible near-infrared spectral groups observed in each population and that Trojans and KBOs share a common formation location. Mixed ices consisting of water, methanol, and ammonia, in mixtures both with and without hydrogen sulfide, were deposited and irradiated with 10 keV electrons. Deposition and initial irradiation were performed at 50 K to simulate formation at 20 au in the early solar system, then heated to Trojan-like temperatures and irradiated further. Finally, irradiation was concluded and resulting samples were observed during heating to room temperature. Results indicated that the presence of sulfur resulted in steeper spectral slopes. Heating through the 140–200 K range decreased the slopes and total reflectance for both mixtures. In addition, absorption features at 410, 620, and 900 nm appeared under irradiation, but only in the H_2S-containing mixture. These features were lost with heating once irradiation was concluded. While the results reported here are consistent with the hypothesis, additional work is needed to address uncertainties and to simulate conditions not included in the present work.

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For preprints, contact `michael.poston@swri.org`
or on the web at `http://adsabs.harvard.edu/abs/2018ApJ...856..124P`

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2004 EW_{95}: A Phyllosilicate-bearing Carbonaceous Asteroid in the Kuiper Belt

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Models of the Solar System's dynamical evolution predict the dispersal of primitive planetesimals from their formative regions among the gas-giant planets due to the early phases of planetary migration. Consequently, carbonaceous objects were scattered both into the outer asteroid belt and out to the Kuiper Belt. These models predict that the Kuiper Belt should contain a small fraction of objects with carbonaceous surfaces, though to date, all reported visible reflectance spectra of small Kuiper Belt Objects (KBOs) are linear and featureless. We report the unusual reflectance spectrum of a small KBO, (120216) 2004 EW_{95}, exhibiting a large drop in its near-UV reflectance and a broad shallow optical absorption feature centered at $\sim$700 nm, which is detected at greater than 4σ significance. These features, confirmed through multiple epochs of spectral photometry and spectroscopy, have respectively been associated with ferric oxides and phyllosilicates. The spectrum bears striking resemblance to those of some C-type asteroids, suggesting that 2004 EW_{95} may share a common origin with those objects. 2004 EW_{95} orbits the Sun in a stable mean motion resonance with Neptune, at relatively high eccentricity and inclination, suggesting it may have been emplaced there by some past dynamical instability. These results appear consistent with the aforementioned model predictions and are the first to show a reliably confirmed detection of silicate material on a small KBO.

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For preprints, contact `tseccull01@qub.ac.uk`
or find it on the web at `http://adsabs.harvard.edu/abs/2018ApJ...855L..26S`

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The Journey of Typhon-Echidna as a Binary System through the Planetary Region

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Among the current population of the 81 known trans-Neptunian binaries (TNBs), only two are in orbits that cross the orbit of Neptune. These are (42355) Typhon-Echidna and (65489) Ceto-Phorcys. In the present work, we focused our analyses on the temporal evolution of the Typhon-Echidna binary system through the outer and inner planetary systems. Using numerical integrations of the N-body gravitational problem, we explored the orbital evolutions of 500 clones of Typhon, recording the close encounters of those clones with planets. We then analysed the effects of those encounters on the binary system. It was found that only $\approx 22\%$ of the encounters with the giant planets were strong enough to disrupt the binary. This binary system has an $\approx 3.6\%$ probability of reaching the terrestrial planetary region over a time scale of approximately 5.4 Myr. Close encounters of Typhon-Echidna with Earth and Venus were also registered, but the probabilities of such events occurring are low ($\approx 0.4\%$). The orbital evolution of the system in the past was also investigated. It was found that in the last 100 Myr, Typhon might have spent most of its time as a TNB crossing the orbit of Neptune. Therefore, our study of the Typhon-Echidna orbital evolution illustrates the possibility of large cometary bodies (radii of 76 km for Typhon and 42 km for Echidna) coming from a remote region of the outer Solar System and that might enter the terrestrial planetary region preserving its binarity throughout the journey.

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For preprints, contact `mattia.galiazzo@univie.ac.at`
or on the web at `http://adsabs.harvard.edu/abs/2018MNRAS.476.5323A`

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The Plutino Population: An Abundance of Contact Binaries

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We observed twelve Plutinos over two separated years with the 4.3m Lowell's Discovery Channel Telescope. Here, we present the first lightcurve data for those objects. Three of them (2014 JL_{80}, 2014 JO_{80}, 2014 JQ_{80}) display a large lightcurve amplitude explainable by a single elongated object, but are most likely caused by a contact binary system due to their lightcurves morphology. These potential contact binaries have rotational periods from 6.3 h to 34.9 h and peak-to-peak lightcurve variability between 0.6 and 0.8 mag. We present partial lightcurves allowing us to constrain the lightcurve amplitude and the rotational period of another nine Plutinos. By merging our data with the literature, we estimate that up to ∼40% of the Plutinos could be contact binaries. Interestingly, we found that all the suspected contact binaries in the 3:2 resonance are small with absolute magnitude H>6 mag. Based on our sample and the literature, up to ∼50% of the small Plutinos are potential contact binaries.

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For preprints, contact `thirouin@lowell.edu` or `ssheppard@carnegiescience.edu`
or on the web at `https://arxiv.org/abs/1804.09695`

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Inclined Asymmetric Libations in Exterior Resonances

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Librational motion in celestial mechanics is generally associated with the existence of stable resonant configurations and signified by the existence of stable periodic solutions and oscillation of critical (resonant) angles. When such an oscillation takes place around a value different than 0 or π, the libration is called *asymmetric*. In the context of the planar circular restricted three-body problem (CRTBP), asymmetric librations have been identified for the exterior mean-motion resonances (MMRs) 1:2, 1:3 etc. as well as for co-orbital motion (1:1). In exterior MMRs the massless body is the outer one. In this paper, we study asymmetric librations in the 3-dimensional space. We employ the computational approach of Markellos (1978) and compute families of asymmetric periodic orbits and their stability. Stable, asymmetric periodic orbits are surrounded in phase space by domains of initial conditions which correspond to stable evolution and librating resonant angles. Our computations were focused on the spatial circular restricted three-body model of the Sun-Neptune-TNO system. We compare our results with numerical integrations of observed TNOs, which reveal that some of them perform 1:2-resonant, inclined asymmetric librations. For the stable 1:2 TNOs librators, we find that their libration seems to be related with the vertically stable planar asymmetric orbits of our model, rather than the 3-dimensional ones found in the present study.

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For preprints, contact `voyatzis@auth.gr`

or on the web at `http://adsabs.harvard.edu/abs/2018CeMDA.130...29V`

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The Non-Uniform and Dynamic Orbits of Trans-Neptunian Objects

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Previously several authors have proposed the existence of one or more giant planets beyond Neptune to explain the non-uniform orbital elements for a dozen or fewer trans-Neptunian objects (TNOs). However, as shown here, it is not just twelve orbits that are non-randomly distributed. The distribution of the longitudes of ascending node, Ω, for all of the known TNOs with perihelia beyond Neptune is also non-uniform, and this cannot be explained by observational bias. However, simulations show that Ω should become uniformly distributed within just three to five million years due to small perturbations from the known planets. Furthermore, the proposed Planet Nine cannot prevent this randomization. These results indicate it is plausible that TNOs have only been in their present orbits for a few million years or less, and there is no reason for giant, undiscovered planets to exist.

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PAPERS RECENTLY SUBMITTED TO JOURNALS

Neptune's 5:2 Resonance in the Kuiper Belt

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Observations of Kuiper belt objects (KBOs) in Neptune's 5:2 resonance present two puzzles: this third order resonance hosts a surprisingly large population, comparable to the prominent populations of Plutinos and Twotinos in the first order 3:2 and 2:1 resonances, respectively; secondly, their eccentricities are concentrated near 0.4. To shed light on these puzzles, we investigate the phase space near this resonance with use of Poincaré sections of the circular planar restricted three body model. We find several transitions in the phase space structure with increasing eccentricity, which we explain with the properties of the resonant orbit relative to Neptune's. The resonance width is narrow for very small eccentricities, but widens dramatically for $e \gtrsim 0.2$, reaching a maximum near $e \approx 0.4$, where it is similar to the maximum widths of the 2:1 and 3:2 resonances. We confirm these results with N-body numerical simulations, including the effects of all four giant planets and a wide range of orbital inclinations of the KBOs. We find that the long term stability of KBOs in this resonance is not strongly sensitive to inclination and that the boundaries of the stable resonant zone are very similar to those found with the simplified three body model, with the caveat that orbits of eccentricity above ~ 0.55 are unstable; such orbits are phase-protected from close encounters with Neptune but not from destabilizing encounters with Uranus. We conclude that the 5:2 resonant KBOs can be understood fairly naturally in light of the phase space structure and basic considerations of long term stability in this resonance.

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Shepherding in a Self-gravitating Disk of Trans-Neptunian Objects

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A relatively massive and moderately eccentric disk of trans-Neptunian objects (TNOs) can effectively counteract apse precession induced by the outer planets, and in the process shepherd highly eccentric members of its population into nearly-stationary configurations which are anti-aligned with the disk itself. We were sufficiently intrigued by this remarkable feature to embark on an extensive exploration of the full spatial dynamics sustained by the combined action of giant planets and a massive trans-Neptunian debris disk. In the process, we identified ranges of disk mass, eccentricity and precession rate which allow apse-clustered populations that faithfully reproduce key orbital properties of the much discussed TNO population. The shepherding disk hypothesis is to be sure complementary to any potential ninth member of the Solar System pantheon, and could obviate the need for it altogether. We discuss its essential ingredients in the context of Solar System formation and evolution, and argue for their naturalness in view of the growing body of observational and theoretical knowledge about self-gravitating disks around massive bodies, extra-solar debris disks included.

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OTHER PAPERS OF INTEREST

Where the Solar System Meets the Solar Neighbourhood: Patterns in the Distribution of Radiants of Observed Hyperbolic Minor Bodies

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Observed hyperbolic minor bodies might have an interstellar origin, but they can be natives of the Solar system as well. Fly-bys with the known planets or the Sun may result in the hyperbolic ejection of an originally bound minor body; in addition, members of the Oort cloud could be forced to follow inbound hyperbolic paths as a result of secular perturbations induced by the Galactic disc or, less frequently, due to impulsive interactions with passing stars. These four processes must leave distinctive signatures in the distribution of radiants of observed hyperbolic objects, both in terms of coordinates and velocity. Here, we perform a systematic numerical exploration of the past orbital evolution of known hyperbolic minor bodies using a full N-body approach and statistical analyses to study their radiants. Our results confirm the theoretical expectations that strong anisotropies are present in the data. We also identify a statistically significant overdensity of high-speed radiants towards the constellation of Gemini that could be due to the closest and most recent known fly-by of a star to the Solar system, that of the so-called Scholz's star. In addition to and besides 1I/2017 U1 ('Oumuamua), we single out eight candidate interstellar comets based on their radiants' velocities.

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For preprints, contact carlosdlfmarcos@gmail.com
or on the web at http://adsabs.harvard.edu/abs/2018MNRAS.476L...1D

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