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DISTANT EKOs

The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

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NEWS & ANNOUNCEMENTS

Kuiper belt presentations and "New Horizons Results at 2014 MU69" special session at the January 2020 AAS meeting

We invite all Kuiper belt researchers to submit abstracts to the upcoming AAS meeting to be held January 4-8 in Honolulu, Hawaii. The meeting will have a significant Kuiper belt component, including a special session featuring the results of New Horizons' encounter with 2014 MU69. Contributed oral and poster presentations more broadly addressing all aspects of the Kuiper belt and related objects are enthusiastically encouraged.

The meeting will have more than 1,000 contributed oral presentations, printed posters, and digital interactive iPosters. This is an excellent opportunity for Kuiper belt researchers to meet with other AAS scientists who don't usually attend DPS or other planetary meetings, and discuss interests that could cut across other fields and develop complementary projects.

Submit your abstract by October 8 at 9:00 pm ET at: `https://aas.org/meetings/aas235`

When selecting the Session Type for your abstract, you will have the option to submit to the special session if desired, which is titled: "New Horizons Results at 2014 MU69". If you submit an abstract to the special session, it does not count against your allotment of regular abstracts for the general meeting. If you submit an abstract for the general Kuiper belt session, select "Solar System" in the pull-down menu for the first category, and for the second category select "Other" and enter the text "Kuiper belt" in the form field below that.

If you have questions, you can contact the session co-chairs Joel Parker (`joel@boulder.swri.edu`) and Cathy Olkin (`colkin@boulder.swri.edu`).

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"Getting Ready for LSST" Workshop at EPSC-DPS 2019

Thursday September 19, 2019 1:30-3:15pm, Geneva, Switzerland - Open to all EPSC-DPS attendees

The Large Synoptic Survey Telescope (LSST; `http://lsst.org`) is an 8-meter, wide-field, ground-based survey program that will survey half the sky every few nights in six optical bands. The LSST telescope is currently being constructed at Cerro Pachón, Chile, with first light expected in 2020 and start of survey operations in 2022. The LSST is slated to make a significant contribution to the study of the Solar System, delivering over a billion highly precise observations of millions of Solar System objects (5 mmag photometry and 10 mas astrometry, per observation, at the bright end). Current estimates show yields ranging from $\sim$100,000 new discoveries of nearby NEOs, to 5.5 million for the main belt, and $\sim$40,000 for KBO populations. The majority of these objects will receive hundreds of observations in multiple bandpasses. This dataset presents tremendous opportunities for Solar System science. This town hall/workshop will overview the science possibilities, report on project status and expected data products, and discuss how to get involved in preparations for science with LSST.

Contact Mario Jurić (`mjuric@astro.washington.edu`) and Ranpal Gill (`rgill@lsst.org`) with any questions

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Icarus Special Issue on the Pluto System, Kuiper Belt, and Kuiper Belt Objects

The deadline has been revised to October 1, 2019 to submit papers for the Icarus special issue on the Pluto System, Kuiper Belt, and Kuiper Belt Objects. This special issue calls for results related to the exploration of the Pluto system, the Kuiper Belt, and Kuiper Belt Objects, particularly by New Horizons, ground-based techniques, and NASA's New Frontiers Data Analysis Program (NFDAP) projects. Papers are solicited from authors across the planetary science community and interdisciplinary papers are welcome. Topics of interest include, but are NOT limited to:

- Geologic mapping and geomorphologic analyses
- Geophysical and geochemical modeling
- Particle or plasma data
- Dynamical or collisional evolution modeling
- Analysis of the composition and photometric properties
- Atmospheric measurements or modeling
- Ground- or space-based telescopic data
- Laboratory analysis of analog materials

The online call for papers can be found here:
`https://tinyurl.com/icarus-pluto-kb-special-issue`

Sincerely, the Guest Editors:
Alan Stern, Rick Binzel, Will Grundy, Kelsi Singer, Oliver White

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COMETS III - A proposed new volume in the Space Science Series
Call for Expressions of Interest

A decade-and-a-half has passed since the publication of Comets II, edited by Michel Festou, Uwe Keller, and Hal Weaver. Substantial advancements in the field by groundbased observers, spacecraft missions, and theoretical modelers amply motivate the organization of Comets III as a proposed new volume in the University of Arizona Press Space Science Series under the editorial production guidance of the Lunar and Planetary Institute. Chapters for Comets III would be due in 2022 with the volume being published in 2023.

An open call is being made for expressions of interest to participate in Comets III as authors, members of the scientific organizing committee, and/or editors. To indicate your interest, download, fill out, and submit an indication of interest form:
`https://www.lpi.usra.edu/publications/books/Comets_III`

Please submit your responses no later than October 15, 2019. Questions may be addressed to the General Editor of the Space Science Series, Richard Binzel (`rpb@mit.edu`).

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Current number of TNOs: 2407 (including Pluto)
Current number of Centaurs/SDOs: 1083
Current number of Neptune Trojans: 23

Out of a total of 3513 objects:
682 have measurements from only one opposition
675 of those have had no measurements for more than a year
366 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

Initial Results From the New Horizons Exploration of 2014 MU_{69}, a Small Kuiper Belt Object

S.A. Stern[1] et al.

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The Kuiper Belt is a distant region of the outer Solar System. On 1 January 2019, the New Horizons spacecraft flew close to (486958) 2014 MU_{69}, a cold classical Kuiper Belt object approximately 30 kilometers in diameter. Such objects have never been substantially heated by the Sun and are therefore well preserved since their formation. We describe initial results from these encounter observations. MU_{69} is a bilobed contact binary with a flattened shape, discrete geological units, and noticeable albedo heterogeneity. However, there is little surface color or compositional heterogeneity. No evidence for satellites, rings or other dust structures, a gas coma, or solar wind interactions was detected. MU_{69}'s origin appears consistent with pebble cloud collapse followed by a low-velocity merger of its two lobes.

Published in: Science, 364, eaaw9771 (2019 May 17)

Available on the web at `http://adsabs.harvard.edu/abs/2019Sci...364.9771S`

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Trans-Neptunian Binaries as Evidence for Planetesimal Formation by the Streaming Instability

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A critical step toward the emergence of planets in a protoplanetary disk consists in accretion of planetesimals, bodies 1-1000 km in size, from smaller disk constituents. This process is poorly understood partly because we lack good observational constraints on the complex physical processes that contribute to planetesimal formation. In the outer solar system, the best place to look for clues is the Kuiper belt, where icy planetesimals survived to this day. Here we report evidence that Kuiper belt planetesimals formed by the streaming instability, a process in which aerodynamically concentrated clumps of pebbles gravitationally collapse into $\sim$100-km-class bodies. Gravitational collapse was previously suggested to explain the ubiquity of equal-size binaries in the Kuiper belt. We analyze new hydrodynamical simulations of the streaming instability to determine the model expectations for the spatial orientation of binary orbits. The predicted broad inclination distribution with $\simeq$80% of prograde binary orbits matches the observations of trans-Neptunian binaries. The formation models which imply predominantly retrograde binary orbits can be ruled out. Given its applicability over a broad range of protoplanetary disk conditions, it is expected that the streaming instability seeded planetesimal formation also elsewhere in the solar system, and beyond.

Published in: Nature Astronomy

For preprints, contact `davidn@boulder.swri.edu`

or on the web at `http://adsabs.harvard.edu/doi/10.1038/s41550-019-0806-z`

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Mutual Orbit Orientations of Transneptunian Binaries

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We present Keplerian orbit solutions for the mutual orbits of 17 transneptunian binary systems (TNBs). For ten of them, the orbit had not previously been known: (60458) 2000 CM_{114}, (119979) 2002 WC_{19}, (160091) 2000 OL_{67}, (160256) 2002 PD_{149}, (469514) 2003 QA_{91}, (469705) ǂKá̦gára, (508788) 2000 CQ_{114}, (508869) 2002 VT_{130}, 1999 RT_{214}, and 2002 XH_{91}. Seven more are systems where the size, shape, and period of the orbit had been published, but new observations have now eliminated the sky plane mirror ambiguity in its orientation: (90482) Orcus, (120347) Salacia-Actaea, 1998 WW_{31}, 1999 OJ_4, 2000 QL_{251}, 2001 XR_{254}, and 2003 TJ_{58}. The dynamical masses we obtain from TNB mutual orbits can be combined with estimates of the objects' sizes from thermal observations or stellar occultations to estimate their bulk densities. The ǂKá̦gára system is currently undergoing mutual events in which one component casts its shadow upon the other and/or obstructs the view of the other. Such events provide valuable opportunities for further characterization of the system. Combining our new orbits with previously published orbits yields a sample of 35 binary orbits with known orientations that can provide important clues about the environment in which outer solar system planetesimals formed, as well as their subsequent evolutionary history. Among the relatively tight binaries, with semimajor axes less than about 5% of their Hill radii, prograde mutual orbits vastly outnumber retrograde orbits. This imbalance is not attributable to any known observational bias. We suggest that this distribution could be the signature of planetesimal formation through gravitational collapse of local density enhancements such as caused by the streaming instability. Wider binaries, with semimajor axes > 5% of their Hill radii, are somewhat more evenly distributed between prograde and retrograde orbits, but with mutual orbits that are aligned or anti-aligned with their heliocentric orbits. This pattern could perhaps result from Kozai-Lidov cycles coupled with tidal evolution eliminating high inclination wide binaries.

To appear in: Icarus

For preprints, contact w.grundy@lowell.edu

or on the web at http://www2.lowell.edu/~grundy/abstracts/2019.TNB_orbits.html

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Colors of Trans-Neptunian Contact Binaries

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The $g'r'i'$ colors of seven likely and potential contact binaries in the Kuiper belt were acquired with the Magellan-Baade telescope and combined with colors from the literature to understand contact binary surfaces. The likely and potential contact binaries discovered in the dynamically Cold Classical population display very-red/ultra-red colors. Such a color is common in this sub-population and infers that the Cold

Classical contact binaries were formed in-situ. The likely contact binaries found in several mean motion resonances with Neptune have colors from moderately to ultra-red suggesting different formation regions. Among the nine contact binaries discovered in resonances, five have very-red/ultra-red colors and four have moderately-red surfaces. Based on the very-red/ultra-red colors and low to moderate inclination of the contact binaries in resonances, these contact binaries are maybe escaped dynamically Cold Classicals that are now trapped in resonances. Moderately-red surfaces are common in diverse sub-populations of the Kuiper belt and thus pinpointing their origin is difficult though they are most likely captured objects formed in the giant planet area. Finally, for the contact binary population we report an anti-correlation between inclination and $g' - r'$, as noticed in the rest of this belt. We also have hints for trends between eccentricity, perihelion distance, rotational period and $g' - r'$, but as we are still dealing with a limited sample, additional data are required to confirm them.

Published in: The Astronomical Journal, 158, 53 (2019 August)
For preprints, contact thirouin@lowell.edu
or on the web at http://adsabs.harvard.edu/abs/2019AJ....158...53T

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A Dearth of Small Members in the Haumea Family Revealed by OSSOS

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While collisional families are common in the asteroid belt, only one is known in the Kuiper belt, linked to the dwarf planet Haumea. The characterization of Haumea's family helps to constrain its origin and, more generally, the collisional history of the Kuiper belt. However, the size distribution of the Haumea family is difficult to constrain from the known sample, which is affected by discovery biases. Here, we use the Outer Solar System Origins Survey (OSSOS) Ensemble to look for Haumea family members. In this OSSOS XVI study we report the detection of three candidates with small ejection velocities relative to the family formation centre. The largest discovery, 2013 UQ_{15}, is conclusively a Haumea family member, with a low ejection velocity and neutral surface colours. Although the OSSOS Ensemble is sensitive to Haumea family members to a limiting absolute magnitude (H_r) of 9.5 (inferred diameter of ∼90 km), the smallest candidate is significantly larger, H_r=7.9. The Haumea family members larger than ≃20 km in diameter must be characterized by a shallow H-distribution slope in order to produce only these three large detections. This shallow size distribution suggests that the family formed in a graze-and-merge scenario, not a catastrophic collision.

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Available on the web at https://doi.org/10.1038/s41550-019-0867-z

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Absolute Colours and Phase Coefficients of Trans-Neptunian Objects: Correlations and Populations

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The study of the visible colours of the trans-Neptunian objects opened a discussion almost 20 years ago which, in spite of the increase in the amount of available data, seems far from subside. Visible colours impose constraints to the current theories of the early dynamical evolution of the Solar System such as the environment of formation, initial surface composition, and how (if) they were scattered to regions closer to the inner planets.

In this paper we present an updated version of our database of absolute colours and relative phase coefficients for 117 objects. We define the absolute colours as the difference of the absolute magnitudes $H_V - H_R$, and the relative phase coefficient as the difference of the slopes of the phase curves $\Delta\beta$. These were obtained joining our own observations plus data from the literature.

The methodology has been introduced in previous works and here we expand in some interesting results, in particular the strong anti-correlation found between $H_V - H_R$ and $\Delta\beta$, which means that redder objects have steeper phase curves in the R filter, while bluer objects have steeper phase curves in the V filter.

We analyse a series of results published in the literature in view of our database, which is free of phase effects, and show that their statistical meaning is not very strong. We point out that phase-colouring and observational errors play an important role in the understanding of these proposed relationships.

Published in: Monthly Notices of the Royal Astronomical Society, 488, 3035 (2019 September)

For preprints, contact `alvarez@on.br`

or on the web at `http://adsabs.harvard.edu/abs/2019MNRAS.488.3035A`

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Photometry of Active Centaurs: Colors of Dormant Active Centaur Nuclei

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We present multiband photometric observations of nine Centaurs. Five of the targets are known active Centaurs (167P/CINEOS, 174P/Echeclus, P/2008 CL94, P/2011 S1, and C/2012 Q1), and the other four are inactive Centaurs belonging to the redder of the two known color subpopulations (83982 Crantor, 121725 Aphidas, 250112 2002 KY14, and 281371 2008 FC76). We measure the optical colors of eight targets and carry out a search for cometary activity. In addition to the four inactive Centaurs, three of the five active Centaurs showed no signs of activity at the time of observation, yielding the first published color measurements of the bare nuclei of 167P and P/2008 CL94 without possible coma contamination. Activity was detected on P/2011 S1 and C/2012 Q1, yielding relatively high estimated mass loss rates of 140 ± 20 and 250 ± 40 kg/s, respectively. The colors of the dormant nuclei are consistent with the

previously-published colors, indicating that any effect of non-geometric scattering from Centaur dust or blanketing debris on the measured colors is minimal. The results of our observations are discussed in the context of the cause of Centaur activity and the color distributions of active and inactive Centaurs. We suggest that the relative paucity of red Centaurs with low-perihelion orbits may not be directly due to the blanketing of the surface by unweathered particulates, but could instead be a result of the higher levels of thermal processing on low-perihelion Centaurs in general.

Published in: The Astronomical Journal, 157, 225 (2019 June)
For preprints, contact iwong@mit.edu
or on the web at http://adsabs.harvard.edu/abs/2019AJ....157..225W

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Apse-alignment in Narrow-eccentric Ringlets and its Implications for the ϵ-ring of Uranus and the Ring System of (10199) Chariklo

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The discovery of ring systems around objects of the outer Solar System provides a strong motivation to apply theoretical models in order to better estimate their physical and orbital parameters, which can constrain scenarios for their origin.

We review the criterion for maintaining apse-alignment across a ring and the balance between the energy input rate provided by a close by satellite and the internal dissipation rate occurring through ring particle collisions that is required to maintain ring eccentricity, as derived from the equations of motion governing the Lagrangian-displacements of the ring-particle orbits. We use the case of the ϵ-ring of Uranus, to calibrate our theoretical discussion and illustrate the basic dynamics governing these types of ring.

In the case of the ring system of (10199) Chariklo, where the evidence that the rings are eccentric is not conclusive, we apply the theory of apse-alignment to derive information about the most plausible combination of values of the surface density and eccentricity-gradient, as well as the masses and locations of their postulated but presently undetected shepherd-satellites.

When the balance conditions that we predict are applied to the ring system of (10199) Chariklo, we are able to estimate the minimum mass of a shepherd satellite required to prevent eccentricity decay, as a function of its orbital location, for two different models of dissipation. We conclude that the satellite mass required to maintain the $m = 1$ eccentric mode in the ring, would be similar or smaller than that needed to confine the rings radially.

Our estimation of the most plausible combinations of eccentricity gradient and surface density consistent with apse-alignment are based on a standard model for the radial form of the surface density distribution, which approximately agrees with the optical depth profile derived by the stellar occultations.

We find a diverse range of solutions, with combinations of eccentricity gradient and surface mass density that tend to minimize required enhanced collisional effects, having adopted estimated values of the form factor of the second degree harmonic of the gravitational potential.

To appear in: Icarus, 325, 113366 (2020 January)
For preprints, contact melita@iafe.uba.ar
or on the web at http://adsabs.harvard.edu/abs/2020Icar..33513366M

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Not a Simple Relationship between Neptune's Migration Speed and Kuiper Belt Inclination Excitation

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We present numerical simulations of giant planet migration in our solar system and examine how the speed of planetary migration affects inclinations in the resulting population of small bodies (test particles) scattered outward and subsequently captured into Neptune's 3:2 mean motion resonance (the Plutinos) as well as the hot classical Kuiper belt population. We do not find a consistent relationship between the degree of test particle inclination excitation and e-folding planet migration timescales in the range $5-50$ Myr. Our results present a counter-example to Nesvorny 2015's finding that the Plutino and hot classical inclinations showed a marked increase with increasing e-folding timescales for Neptune's migration. We argue that these differing results are likely due to differing secular architectures of the giant planets during and after migration. Small changes in the planets' initial conditions and differences in the numerical implementation of planet migration can result in different amplitudes of the planets' inclination secular modes, and this can lead to different final inclination distributions for test particles in the simulations. We conclude that the observed large inclination dispersion of Kuiper belt objects does not require Neptune's migration to be slow; planetary migration with e-folding timescales of 5, 10, 30, and 50 Myr can all yield inclination dispersions similar to the observed Plutino and hot classical populations, with no correlation between the degree of inclination excitation and migration speed.

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For preprints, contact `kvolk@lpl.arizona.edu`

or on the web at `http://adsabs.harvard.edu/abs/2019AJ....158...64V`

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Chaos in the Inert Oort Cloud

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Context: Distant trans-Neptunian objects are subject to planetary perturbations and galactic tides. The former decrease with the distance, while the latter increase. In the intermediate regime where they have the same order of magnitude (the 'inert Oort cloud'), both are weak, resulting in very long evolution timescales. To date, three observed objects can be considered to belong to this category.

Aims: We aim to provide a clear understanding of where this transition occurs, and to characterise the long-term dynamics of small bodies in the intermediate regime: relevant resonances, chaotic zones (if any), and timescales at play.

Methods: The different regimes are explored analytically and numerically. We also monitored the behaviour of swarms of particles during 4.5 Gyrs in order to identify which of the dynamical features are discernible in a realistic amount of time.

Results: There exists a tilted equilibrium plane (Laplace plane) about which orbits precess. The dynamics is integrable in the low and high semi-major axis regimes, but mostly chaotic in between. From about 800 to 1100 astronomical units (au), the chaos covers almost all the eccentricity range. The diffusion timescales are large, but not to the point of being indiscernible in a 4.5 Gyrs duration: the perihelion distance can actually vary from tens to hundreds of au. Orbital variations are damped near the ecliptic (where previous studies focussed), but favoured in specific ranges of inclination corresponding to well-defined resonances. Moreover, starting from uniform distributions, the orbital angles cluster after 4.5 Gyrs for semi-major axes larger than 500 au, because of a very slow differential precession.

Conclusions: Even if it is characterised by very long timescales, the inert Oort cloud mostly features chaotic regions; it is therefore much less inert than it appears. Orbits can be considered inert over 4.5 Gyrs only in small portions of the space of orbital elements, which include (90377) Sedna and 2012 VP113. Effects of the galactic tides are discernible down to semi-major axes of about 500 au. We advocate including the galactic tides in simulations of distant trans-Neptunian objects, especially when studying the formation of detached bodies or the clustering of orbital elements.

To appear in: Astronomy & Astrophysics
For preprints, contact melaine.saillenfest@obspm.fr
or on the web at https://arxiv.org/abs/1908.05175

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A New Two-Molecule Combination Band as Diagnostic of Carbon Monoxide Diluted in Nitrogen Ice On Triton

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[7] Universite Grenoble Alpes, Grenoble, France

A combination band due to a mechanism whereby a photon excites two or more vibrational modes (*e.g.* a bend and a stretch) of an individual molecule is commonly seen in laboratory and astronomical spectroscopy. Here, we present evidence of a much less commonly seen combination band – one where a photon simultaneously excites two adjacent molecules in an ice. In particular, we present near-infrared spectra of laboratory CO/N_2 ice samples where we identify a band at 4467.5 cm^{-1} (2.239 μm) that results from single photons exciting adjacent pairs of CO and N_2 molecules. We also present a near-infrared spectrum of Neptune's largest satellite Triton taken with the Gemini-South 8.1 meter telescope and the Immersion Grating Infrared Spectrograph (IGRINS) that shows this 4467.5 cm^{-1} (2.239 μm) CO-N_2 combination band. The existence of the band in a spectrum of Triton indicates that CO and N_2 molecules are intimately mixed in the ice rather than existing as separate regions of pure CO and pure N_2 deposits. Our finding is important because CO and N_2 are the most volatile species on Triton and so dominate seasonal volatile transport across its surface. Our result will place constraints on the interaction between the surface and atmosphere of Triton.

Published in: The Astronomical Journal, 158, 17 (2019 July)
For preprints, contact Stephen.Tegler@nau.edu
or on the web at http://adsabs.harvard.edu/abs/2019AJ....158...17T

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Surface Properties of Large TNOs: Expanding the Study to Longer Wavelengths with the James Webb Space Telescope

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The largest trans-Neptunian objects (TNOs) represent an extremely diverse collection of primitive bodies in the outer solar system. The community typically refers to these objects as "dwarf planets", though the IAU acknowledges only four TNOs officially as such: Pluto, Eris, Makemake, and Haumea. We present a list of 36 potential candidates for reclassification as dwarf planets, namely candidate dwarf planets (CDPs), which cover a wide range of sizes, geometric albedos, surface colors and probably, composition. Understanding the properties across this population, and how those properties change with size, will yield useful constraints on the environment in which these TNOs formed, as well as their dynamical evolution, and bulk interior composition. TNO surface characteristics are ideal for study with the James Webb Space Telescope (JWST), which provides imaging and spectroscopic capabilities from ∼0.6-28 μm. The four available science instruments, MIRI, NIRCam, NIRISS, and NIRSpec, and their capabilities for the study of TNOs, are presented. JWST will expand on the wavelength range observable from the ground in the near-infrared (0.6-5 μm) for compositional studies and will open a new window on TNOs in the mid-infrared (5-28 μm) for thermal characterization.

To appear in: "The Trans-Neptunian Solar System" (Editors: Dina Prialnik, Maria Antonietta Barucci, Leslie Young, Elsevier)

For preprints, contact `npinilla@ucf.edu`

or on the web at `https://arxiv.org/abs/1905.12320`

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Lower Atmosphere and Pressure Evolution on Pluto from Ground-based Stellar Occultations, 1988-2016

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Context: The tenuous nitrogen (N_2) atmosphere on Pluto undergoes strong seasonal effects due to high obliquity and orbital eccentricity, and has recently (July 2015) been observed by the New Horizons spacecraft.

Aims: The main goals of this study are (i) to construct a well calibrated record of the seasonal evolution of surface pressure on Pluto and (ii) to constrain the structure of the lower atmosphere using a central flash observed in 2015.

Methods: Eleven stellar occultations by Pluto observed between 2002 and 2016 are used to retrieve atmospheric profiles (density, pressure, temperature) between altitude levels of 5 and 380 km (i.e. pressures from 10 μbar to 10 nbar).

Results: (i) Pressure has suffered a monotonic increase from 1988 to 2016, that is compared to a seasonal volatile transport model, from which tight constraints on a combination of albedo and emissivity of N_2 ice are derived. (ii) A central flash observed on 2015 June 29 is consistent with New Horizons REX profiles, provided that (a) large diurnal temperature variations (not expected by current models) occur over Sputnik Planitia; and/or (b) hazes with tangential optical depth of 0.3 are present at 4-7 km altitude levels; and/or

(c) the nominal REX density values are overestimated by an implausibly large factor of 20%; and/or (d) higher terrains block part of the flash in the Charon facing hemisphere.

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For preprints, contact josselin.desmars@obspm.fr
or available online at: http://adsabs.harvard.edu/abs/2019A%26A...625A..42M

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Pluto's Ephemeris from Ground-based Stellar Occultations (1988-2016)

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From 1988 to 2016, several stellar occultations have been observed to characterise Pluto's atmosphere and its evolution. From each stellar occultation, an accurate astrometric position of Pluto at the observation epoch is derived. These positions mainly depend on the position of the occulted star and the precision of the timing.

We present 19 Pluto's astrometric positions derived from occultations from 1988 to 2016. Using Gaia DR2 for the positions of the occulted stars, the accuracy of these positions is estimated at 2-10 mas, depending on the observation circumstances. From these astrometric positions, we derive an updated ephemeris of Pluto's system barycentre using the NIMA code.

The astrometric positions were derived by fitting the light curves of the occultation by a model of Pluto's atmosphere. The fits provide the observed position of the centre for a reference star position. In most cases other publications provided the circumstances of the occultation such as the coordinates of the stations, timing, and impact parameter, i.e. the closest distance between the station and centre of the shadow. From these parameters, we used a procedure based on the Bessel method to derive an astrometric position.

We derive accurate Pluto's astrometric positions from 1988 to 2016. These positions are used to refine the orbit of Pluto's system barycentre providing an ephemeris, accurate to the milliarcsecond level, over the period 2000-2020, allowing for better predictions for future stellar occultations.

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The Trans-Neptunian Object (84922) 2003 VS_2 Through Stellar Occultations

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We present results from three world-wide campaigns that resulted in the detections of two single-chord and one multi-chord stellar occultations by the Plutino object (84922) 2003 VS_2. From the single-chord occultations we obtained accurate astrometric positions for the object, while from the multi-chord occultation on November 7th, 2014, we obtained the parameters of the best-fitting ellipse to the limb of the body at the time of occultation, with equatorial diameter 627.6 ± 14.2 km, apparent oblateness $0.190^{+0.052}_{-0.060}$ and equivalent area diameter of $564.8^{+33.8}_{-30.2}$ km. We also obtained short-term photometry data for the body in order to derive its rotational phase during the occultation. This allows us to reconstruct the three-dimensional shape of the body, with principal semi-axes $a = 313.8 \pm 7.1$ km, $b = 265.5^{+8.8}_{-9.8}$ km, and $c = 247.3^{+26.6}_{-43.6}$ km, which is not consistent with a Jacobi triaxial equilibrium figure. The derived volume equivalent diameter of $548.3^{+29.5}_{-44.6}$ km is about 5% larger than the radiometrically diameter of 2003 VS_2 derived from Herschel data of 523 ± 35 km, but still compatible with it within error bars. From those results we can also derive the geometric albedo ($0.123^{+0.015}_{-0.014}$) for the Plutino. The disappearances and reappearances of the star during the occultations do not show any compelling evidence for a global atmosphere, nor secondary features (e.g. rings or satellite) around the main body.

To appear in: The Astronomical Journal

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or available online at: `http://arxiv.org/abs/1908.06645`

OTHER PAPERS OF INTEREST

Maximizing LSST Solar System Science: Approaches, Software Tools, and Infrastructure Needs

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The Large Synoptic Survey Telescope (LSST) is expected to increase known small solar system object populations by an order of magnitude or more over the next decade, enabling a broad array of transformative solar system science investigations to be performed. In this white paper, we discuss software tools and infrastructure that we anticipate will be needed to conduct these investigations and outline possible approaches for implementing them. Feedback from the community or contributions to future updates of this work are welcome. Our aim is for this white paper to encourage further consideration of the software development needs of the LSST solar system science community, and also to be a call to action for working to meet those needs in advance of the expected start of the survey in late 2022.

Available online at: `https://arxiv.org/abs/1906.11346`

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History of the Terminal Cataclysm Paradigm: Epistemology of a Planetary Bombardment That Never (?) Happened

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This study examines the history of the paradigm concerning a lunar (or solar-system-wide) terminal cataclysm (also called "Late Heavy Bombardment" or LHB), a putative, brief spike in impacts at 3.9 Ga ago, preceded by low impact rates. We examine origin of the ideas, why they were accepted, and why the ideas are currently being seriously revised, if not abandoned. The paper is divided into the following sections:
Overview of paradigm.
Pre-Apollo views (1949-1969).
Initial suggestions of cataclysm (ca. 1974).
Ironies.
Alternative suggestions, megaregolith evolution (1970s).
Impact melt rocks "establish" cataclysm (1990).
Imbrium redux (ca. 1998).
Impact melt clasts (early 2000s).
Dating of front-side lunar basins?
Dynamical models "explain" the cataclysm (c. 2000s).
Asteroids as a test case.
Impact melts predating 4.0 Ga ago (ca. 2008-present.).
Biological issues.
Growing doubts (ca. 1994-2014).
Evolving Dynamical Models (ca. 2001-present).
Connections to lunar origin.
Dismantling the paradigm (2015-2018).
"Megaregolith Evolution Model" for explaining the data.
Conclusions and new directions for future work.

The author hopes that this open-access discussion may prove useful for classroom discussions of how science moves forward through self-correction of hypotheses.

Published in: Geosciences 9, 285
For preprints, contact `hartmann@psi.edu`
or on the web at `https://www.mdpi.com/2076-3263/9/7/285`

THESES

Detection of Kuiper Belt Objects by Stellar Occultation

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For this occultation survey, we used the 1.2 m UK Schmidt Telescope (UKST) in conjunction with the 6dF multi-fibre spectrograph. The 6dF was operated in a new, specially devised through mode to achieve a very fast 100 Hz acquisition rate, the fastest used on any occultation survey to date. A fast acquisition rate is required to achieve good event resolution.

Our occultation survey is one of the few large surveys of the ecliptic capable of detecting distant sub-kilometre radius KBOs. It is concentrated specifically on the ecliptic, with the acquired dataset all coming from a region that includes Neptune's L4 (leading) Lagrangian point. It contains ∼6,700 star hours of data, sufficient to provide a meaningful restriction on the upper limit of the small KBO population. It is sensitive to detection KBOs down to ∼250 metres radius, representing a two orders of magnitude improvement over what can be achieved by direct observation.

We report one detection for a KBO of radius ∼430 metres at a distance of 46 AU. This 15 data point event represents the best resolved occultation event from a small KBO to date, and arguably the first credible result obtained from ground based observations.

From this result we further constrain the implied population density for such objects within ±2 degrees of the ecliptic, including within the Neptune L4 Lagrangian region. The results presented here also prove the viability of using a 1-metre class telescope for this type of work.

Dissertation directed by Prof. Michael C.B. Ashley
Ph.D. awarded November 2018 from University of NSW
Available on the web at
`http://unsworks.unsw.edu.au/fapi/datastream/unsworks:54259/SOURCE02?view=true`

CONFERENCE CONTRIBUTIONS

Kuiper Belt Presentations at the EPSC-DPS Joint Meeting

2019 September 15-20, Geneva, Switzerland

More information at the meeting website: `https://www.epsc-dps2019.eu`

Below is a selection of presentations about the Kuiper belt and relatives (Pluto, Centaurs, etc.) that I have culled – perhaps imperfectly – from the EPSC-DPS program.

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ORAL PRESENTATIONS

Monday, September 16

Session SB1: Surveys of discovery and characterisation of small bodies including ESA's Gaia

- 14:00. New census of Hilda, Jovian Trojan, Centaur and transneptunian object light curves from K2 measurements [Kiss]

Session SB2: Laboratory measurements and models for cometary, asteroidal, dwarf planet and meteoric material studies including organic matter studies

- 14:50. Chemical composition of Pluto's aerosols analogues [Jovanovic]

Tuesday, September 17

Session EXO5/TP19/OPS6: Aerosols and clouds in planetary atmospheres

- 14:15. Global Retrieval of Pluto's Haze [Yung]

Session TP13/OPS12/SB13: Planetary Dynamics I: Shape, Gravity, Orbit, Tides, and Rotation from Observations and Models

- 16:30. Rotation States of Pluto's Small Moons and the Search for Spin-Orbit Resonances [Showalter]
- 16:45. On the asphericity of the figures of Pluto and Charon. Triaxial approximation [Borukha]

Wednesday, September 18

Session EX06: Formation and Evolution of Planetary Systems: From Disks to Planets

- 14:40. The fate of planetesimal discs in young open clusters: implications for 1I/'Oumuamua, the Kuiper belt, the Oort cloud and more [Hands]

Thursday, September 19

Session OPS3/EXO16: Ocean Worlds and Icy Moons

- 11:30 Pluto surface composition from spectral model inversion with metaheuristics [Gabasova]

Session SB7: Collisions among small bodies, on planetary surfaces and with atmospheres (meteors)

- 14:05. The Kuiper belt vs the asteroid belt: Insights from the New Horizons mission results [Singer]

Session MIT1: Upcoming and Future Planetary Missions and Instrumentation (L Class, M Class, New Frontiers, Discovery, etc.)

- 17:00. Chimera: A Mission of Discovery to the First Centaur [Harris]

Friday, September 20

Session SB5: Trans-Neptunian objects and their dust environment, Pluto, 2014 MU69, and Centaurs

- 08:30. Geology and Geophysics of 2014 MU69: New Horizons Flyby Results [Spencer]
- 08:40. The Color of 2014 MU69 from New Horizons[Olkin]
- 08:50. The Shape and Pole of (486958) 2014 MU69 [Porter]
- 09:00. Latitude Zones and Seasons on 2014 MU 69 'Ultima Thule' [Earle]
- 09:10. Near surface temperature modelling of 2014 MU69 [Umurhan]
- 09:20. Albedo Map of Kuiper Belt Object 2014 MU69 and Comparison with Cognate Solar System Objects [Hofgartner]
- 09:30. The Geophysical Environment of (486958) 2014 MU69 [Keane]
- 09:40. Scarp Retreat on MU69: Evidence and Implications for Composition and Structure [Moore]
- 09:50. On the Origin of the Remarkable Contact Binary (486958) 2014 MU69 ("Ultima Thule") [McKinnon]
- 10:30. Photometric properties of Pluto's main surface units [Protopapa]
- 10:40. Pluto dark refractory material: a close look at composition and origin [Dalle Ore]
- 10:50. Testing tholins as analogs of the dark reddish material covering the cthulhu region [Fayolle]
- 11:00. Pluto's Hypervolatile Surface Ices Sourced From KBO Amorphous Water Ice Composites [Lisse]
- 11:10. Elevation-dependent CH4 condensation on Pluto: what are the origins of the observed CH4 snow-capped mountains? [Bertrand]
- 11:20. Pluto's Minimum Surface Pressure and Implications for Haze Production [Johnson]
- 11:30. A Fourier-Optics Approach to Modeling the 15-AUG-2018 Pluto Occultation [Young]
- 11:40. The stellar occultation by the TNO (174567) Varda of September 10, 2018: size, shape and atmospheric constraints [Braga-Ribas]
- 11:50. Makemake's thermal emission reconsidered [Farkas-Takacs]
- 13:30. Constraining Neptune's Migration: Cold Classicals in the 2:1 Resonance? [Pike]
- 13:40. A new OSSOS-based model of the classical Kuiper belt [Petit]
- 13:50. Collisions in the classical Kuiper belt [Abedin]
- 14:00. A compositional study of trans-Neptunian objects using photometric data beyond 2.2 μm [Fernández-Valenzuela]
- 14:10. The secret to a perfect tan on TNOs: alcohol, water and Sun radiation [Urso]
- 14:20. Modeling the Color Distribution of Kuiper Belt Objects [Nesvorny]
- 14:30. A Potential New Surface Type in the Kuiper Belt [Schwamb]
- 14:40. Chaos in the inert Oort cloud [Saillenfest]
- 14:50. Probing the Very Distant Solar System: A Deep, Wide and Uniform Survey for Extreme Trans-Neptunian Objects [Sheppard]
- 15:30. Contact binaries in the trans-Neptunian population: location, physical and rotational properties [Thirouin]
- 15:40. Optimal strategy for KBO lightcurve studies from the ground [Kokotanekova]
- 15:50. Manwë -Thorondor: A tertiary system in the Kuiper Belt? [Rabinowitz]
- 16:00. Orbital evolution of Centaurs and their transition to Jupiter family comets: implications for the onset of cometary activity [Sarid]
- 16:20. Characterization of material around (2060) Chiron from a 2011 stellar occultation [Sickafoose]

- 16:30. The multi-chord stellar occultation by the Transneptunian object (38628) Huya on March 18th 2019 [Santos-Sanz]
- 16:40. A stellar occultation by a small plutino with RECON [Leiva]
- 16:50. Three Stellar Occultations by the Plutino Object (84922) 2003 VS2 [Benedetti-Rossi]

Session SB6: Imaging, photometry, polarimetry, and spectroscopy of small bodies and dust
- 16:20. Col-OSSOS: A Compositional Interpretation of Kuiper Belt Spectra [Fraser]

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POSTER PRESENTATIONS

Session EXO5/TP19/OPS6: Aerosols and clouds in planetary atmospheres
- Laboratory simulation of Pluto's atmospheric chemistry [Jovanovic]

Session LP3/MIT: Late posters Missions, Instrumentation, Techniques
- Centaurus: Exploring Centaurs and More, Messengers from the Era of Planet Formation [Singer]

Session SB1: Surveys of discovery and characterisation of small bodies including ESA's Gaia
- Studying Centaur and Trans-Neptunian objects using stellar occultation: precise astrometric positions [Rommel]

Session SB2: Laboratory measurements and models for cometary, asteroidal, dwarf planet and meteoric material studies including organic matter studies
- Thinking outside the 'ice' box; grain size changes of solid nitrogen and its effects on the surface of Pluto [Maynard-Casely]
- Status of the Transneptunian Automated Occultation Survey (TAOS II) [Lehner]

Session SB5: Trans-Neptunian objects and their dust environment, Pluto, 2014 MU69, and Centaurs
- New Horizons REX Radiometry at 2014 MU69 [Linscott]
- Comparing KBO (486958) MU69 to JFC Nuclei [Weaver]
- Limb topography of MU69 [Bierson]
- Stereo Topography of KBO (486958) 2014 MU69 [Beyer]
- Topography of Pits & Troughs on Ultima Thule (2014 MU69) from New Horizons [Schenk]
- Impact craters on 2014 MU69: The geologic history of MU69 and Kuiper belt object size-frequency distributions [Singer]
- Impact fluxes on 2014 MU69 and Pluto and their variations over secular timescales [JeongAhn]
- MU69's Hidden Side: Photography of the Team During the New Horizons Flyby [Throop]
- Limits on Rings and Debris Around 2014 MU69 from New Horizons [Throop]
- Haumea cluster versus Haumea family [Ortiz]
- The Orbit of the Satellite Around Dwarf Planet 2013 FY27 [Sheppard]
- New Horizons REX Radiometry at Pluto and Charon [Bird]
- Pluto's Ultraviolet Spectrum, Airglow Emissions, and Surface Reflectance [Steffl]
- Atmosphere/Surface/Subsurface Interaction at Pluto [Young]
- Photochemical Model of Pluto's Atmosphere and Ionosphere [Krasnopolsky]
- The Pluto System at True Opposition [Verbiscer]

- Pluto at opposition: The Palomar Adaptive Optics Campaign [Buratti]
- Pluto's ephemeris from stellar occultations [Desmars]
- Lightcurves of the August 15, 2018 Pluto occultation from the San Pedro Martir observatory [Silva]
- Stable 'Islands' in the chaotic Centaurs' region and possible physical consequences [Galiazzo]
- Looking for a primordial fingerprint in known Long Period Comets [Higuchi]
- Memory of long-period comets, short-period comets and Centaurs [Emel'yanenko]
- No active Centaurs in the Outer Solar System Origins Survey [Cabral]
- Centaur Exploration Workshop 2019 and its Deliverables: The Roots of Activity [Womack]
- Accretion and thermal evolution of TransNeptunian Objects: A new model [Métayer]
- Explanation of the shape of 'Oumuamua by interstellar dust erosion [Vavilov]
- Photometry and radiometric modeling of Transneptunian objects in support of the Herschel key program 'TNOs are Cool' [Masoumzadeh]
- Orbital solutions for the OSSOS binaries [Noyelles]
- Early formation of satellites around 1000 km-sized trans-Neptunian objects via giant impacts [Arakawa]
- The Deep Ecliptic Exploration Project (DEEP): A new NOAO survey of the faint outer Solar System [Trilling]
- Study of the dynamics of the 1/3 mean-motion resonance between trans-Neptunian objects and Neptune [Alves do Carmo]
- The Solar System Origins Legacy Survey: Motivation, Design, and Initial Results [Parker]
- Classification of TNOs detected by stellar occultation using a SVM [Castro]
- The Outer Solar System Perihelion Gap [Oldroyd]
- A Pan-STARRS Search for Distant Planets [Holman]

Session SB6: Imaging, photometry, polarimetry, and spectroscopy of small bodies and dust

- Observing Transneptunian Objects with JWST/NIRSpec [Guilbert-Lepoutre]

Session SB10: Computational and experimental astrophysics of small bodies, planets, and granular system: open questions, challenges, new techniques and models

- Effect of the planetesimal disk on the positions of the secular resonances in the primordial Kuiper Belt [Baguet]

Session LP4/SB: Late posters Small Bodies (comets, KBOs, rings, asteroids, meteorites, dust)

- HST Search for Binary Neptune Trojans: Upper Limits and Comparison to Other Transneptunian Populations [Noll]

Session: TP16: Collisions from small bodies to planetary scales

- Dynamical evolution of Centaurs and impacts with planets [Galiazzo]

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:
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⋆ Status reports of on-going programs
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⋆ Table of contents/outlines of books
⋆ Announcements for conferences
⋆ Job advertisements
⋆ General news items deemed of interest to the Kuiper belt community

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