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DISTANT EKOs

The Kuiper Belt Electronic Newsletter

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CONTENTS

NEWS & ANNOUNCEMENTS

There were no new TNO discoveries announced since the previous issue of *Distant EKOs*, but there were 4 new Centaur/SDO discoveries:

2010 JO179, 2017 QF33, 2016 QF86, 2017 RG16

Reclassified objects:

2014 SE350 (TNO → SDO)
2015 BZ517 (TNO → SDO)

Objects recently assigned numbers:

2010 OO127 = (499514)
2010 PL66 = (499522)
2013 GR136 = (500828)
2013 GT136 = (500829)
2013 GU136 = (500830)
2013 GV136 = (500831)
2013 GZ136 = (500832)
2013 GD137 = (500833)
2013 GK137 = (500834)
2013 GN137 = (500835)
2013 GQ137 = (500836)
2013 GT137 = (500837)
2013 GV137 = (500838)
2013 GW137 = (500839)
2013 GA138 = (500840)
2013 HT156 = (500856)
2013 JD64 = (500876)
2013 JE64 = (500877)
2013 JG64 = (500878)
2013 JH64 = (500879)
2013 JJ64 = (500880)
2013 JM64 = (500881)
2013 JN64 = (500882)
2013 JJ65 = (500883)
2013 JK65 = (500884)
2013 JL65 = (500885)
2013 JN65 = (500886)
2013 JO65 = (500887)
2013 JP65 = (500888)
2013 SA87 = (501105)
2013 TC146 = (501214)
2014 JJ80 = (501546)
2014 OB394 = (501581)
2015 PN291 = (503273)

Objects recently assigned names:

1999 TC36 = Lempo
1999 XX143 = Aphidas

Current number of TNOs: 1814 (including Pluto)
Current number of Centaurs/SDOs: 721
Current number of Neptune Trojans: 17

Out of a total of 2552 objects:
707 have measurements from only one opposition
698 of those have had no measurements for more than a year
343 of those have arcs shorter than 10 days
(for more details, see: `http://www.boulder.swri.edu/ekonews/objects/recov_stats.jpg`)

PAPERS ACCEPTED TO JOURNALS

The Pluto System After the New Horizons flyby

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In July 2015, NASA's New Horizons mission performed a flyby of Pluto, revealing details about the geology, surface composition and atmospheres of this world and its moons that are unobtainable from Earth. With a resolution as small as 80 metres per pixel, New Horizons' images identified a large number of surface features, including a large basin filled with glacial ices that appear to be undergoing convection. Maps of surface composition show latitudinal banding, with non-volatile material dominating the equatorial region and volatile ices at mid and polar latitudes. This pattern is driven by the seasonal pattern of solar insolation. New Horizons' atmospheric investigation found the temperature of Pluto's upper atmosphere to be much cooler than previously modelled. Images of forward-scattered sunlight revealed numerous haze layers extending up to 200 km from the surface. These discoveries have transformed our understanding of icy worlds in the outer Solar System, demonstrating that even at great distances from the Sun, worlds can have active geologic processes. This Review addresses our current understanding of the Pluto system and places it in context with previous investigations.

Published in: Nature Astronomy

Available on the web at `https://www.nature.com/articles/s41550-017-0257-3`

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The Pluto System After New Horizons

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The discovery of Pluto in 1930 presaged the discoveries of both the Kuiper Belt and ice dwarf planets — the third class of planets in our solar system. From the 1970s to the 1990s, numerous fascinating attributes of this binary planet were discovered, including multiple surface volatile species, the presence of its largest satellite Charon, and its atmosphere. These attributes, and the 1990s discovery of the Kuiper Belt and Pluto's cohort of small Kuiper Belt planets motivated the spacecraft exploration of Pluto. That mission, called New Horizons (NH), revolutionized our knowledge of Pluto and its system of moons in mid-2015. Beyond providing rich geological, compositional, and atmospheric datasets, NH demonstrated that Pluto has been surprisingly geologically and climatologically active throughout the past 4+ Gyr, and that the planet exhibits a surprisingly complex range of atmospheric phenomenology and geological expressions that rival Mars in their richness.

To appear in: Annual Reviews of Astronomy and Astrophysics

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The New Horizons and Hubble Space Telescope Search For Rings, Dust, and Debris in the Pluto-Charon System

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We conducted an extensive search for dust or debris rings in the Pluto-Charon system before, during, and after the New Horizons encounter in July 2015. Methodologies included attempting to detect features by back-scattered light during the approach to Pluto (phase angle $\alpha \sim 15°$), *in situ* detection of impacting particles, a search for stellar occultations near the time of closest approach, and by forward-scattered light imaging during departure ($\alpha \sim 165°$). An extensive search using the Hubble Space Telescope (HST) prior to the encounter also contributed to the final ring limits. No rings, debris, or dust features were observed, but our new detection limits provide a substantially improved picture of the environment throughout the Pluto-Charon system. Searches for rings in back-scattered light covered the range 35,000–250,000 km from the system barycenter, a zone that starts interior to the orbit of Styx, the innermost minor satellite, and extends out to four times the orbital radius of Hydra, the outermost known satellite. We obtained our firmest limits using data from the New Horizons LORRI camera in the inner half of this region. Our limits on the normal I/F of an unseen ring depends on the radial scale of the rings: 2×10^{-8} (3σ) for 1500 km wide rings, 1×10^{-8} for 6000 km rings, and 7×10^{-9} for 12,000 km rings. Beyond $\sim 100,000$ km from Pluto, HST observations limit normal I/F to $\sim 8 \times 10^{-8}$. Searches for dust features from forward-scattered light extended from the surface of Pluto to the Pluto-Charon Hill sphere ($r_{\rm Hill} = 6.4 \times 10^6$ km). No evidence for rings or dust clouds was detected to normal I/F limits of $\sim 8.9 \times 10^{-7}$ on $\sim 10^4$ km scales. Four stellar occultation observations also probed the space interior to Hydra, but again no dust or debris were detected. The Student Dust Counter detected one particle impact 3.6×10^6 km from Pluto, but this is consistent with the interplanetary space environment established during the cruise of New Horizons. Elsewhere in the solar system, small moons commonly share their orbits with faint dust rings. Our results support recent dynamical studies suggesting that small grains are quickly lost from the Pluto-Charon system due to solar radiation pressure, whereas larger particles are orbitally unstable due to ongoing perturbations by the known moons.

To appear in: Icarus

Available on the web at `https://arxiv.org/abs/1709.07981`

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The Size, Shape, Density and Ring of the Dwarf Planet Haumea from a Stellar Occultation

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Haumea – one of the four known trans-Neptunian dwarf planets – is a very elongated and rapidly rotating body. In contrast to other dwarf planets, its size, shape, albedo and density are not well constrained. The Centaur Chariklo was the first body other than a giant planet known to have a ring system, and the Centaur Chiron was later found to possess something similar to Chariklo's rings. Here we report observations from multiple Earth-based observatories of Haumea passing in front of a distant star (a multi-chord stellar occultation). Secondary events observed around the main body of Haumea are consistent with the presence of a ring with an opacity of 0.5, width of 70 kilometres and radius of about 2,287 kilometres. The ring is coplanar with both Haumea's equator and the orbit of its satellite Hi'iaka. The radius of the ring places it close to the 3:1 mean-motion resonance with Haumea's spin period – that is, Haumea rotates three times on its axis in the time that a ring particle completes one revolution. The occultation by the main body provides an instantaneous elliptical projected shape with axes of about 1,704 kilometres and 1,138 kilometres. Combined with rotational light curves, the occultation constrains the three-dimensional orientation of Haumea and its triaxial shape, which is inconsistent with a homogeneous body in hydrostatic equilibrium. Haumea's largest axis is at least 2,322 kilometres, larger than previously thought, implying an upper limit for its density of 1,885 kilograms per cubic metre and a geometric albedo of 0.51, both smaller than previous estimates. In addition, this estimate of the density of Haumea is closer to that of Pluto than are previous estimates, in line with expectations. No global nitrogen- or methane-dominated atmosphere was detected.

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For preprints, contact `psantos@iaa.es`

or on the web at `http://www.nature.com/nature/journal/v550/n7675/full/nature24051.html`

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The Structure of Chariklo's Rings from Stellar Occultations

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Two narrow and dense rings (called C1R and C2R) were discovered around the Centaur object (10199) Chariklo during a stellar occultation observed on 2013 June 3. Following this discovery, we planned observations of several occultations by Chariklo's system in order to better characterize the physical properties of the ring and main body. Here, we use 12 successful occultations by Chariklo observed between 2014 and 2016. They provide ring profiles (physical width, opacity, edge structure) and constraints on the radii and pole position. Our new observations are currently consistent with the circular ring solution and pole position, to within the ± 3.3 km formal uncertainty for the ring radii derived by Braga-Ribas et al. The six resolved C1R profiles reveal significant width variations from ~ 5 to 7.5 km. The width of the fainter ring C2R is less constrained, and may vary between 0.1 and 1 km. The inner and outer edges of C1R are consistent with infinitely sharp boundaries, with typical upper limits of one kilometer for the transition zone between the ring and empty space. No constraint on the sharpness of C2R's edges is available. A 1σ upper limit of ~ 20 m is derived for the equivalent width of narrow (physical width < 4 km) rings up to distances of 12,000 km, counted in the ring plane.

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Preprints on the web at `https://arxiv.org/abs/1706.00207`

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Size and Shape of Chariklo from Multi-epoch Stellar Occultations

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We use data from five stellar occultations observed between 2013 and 2016 to constrain Chariklo's size and shape, and the ring reflectivity. We consider four possible models for Chariklo (sphere, Maclaurin spheroid, tri-axial ellipsoid and Jacobi ellipsoid) and we use a Bayesian approach to estimate the corresponding parameters. The spherical model has a radius $R = 129 \pm 3$ km. The Maclaurin model has equatorial and polar radii $a = b = 143^{+3}_{-6}$ km and $c = 96^{+14}_{-4}$ km, respectively, with density 970^{+300}_{-180} kg m^{-3}. The ellipsoidal model has semiaxes $a = 148^{+6}_{-4}$ km, $b = 132^{+6}_{-5}$ km and $c = 102^{+10}_{-8}$ km. Finally, the Jacobi model has semiaxes a=157±4 km, b=139± 4 km and c=86±1 km, and density 796^{+2}_{-4} kg m^{-3}. Depending on the model, we obtain topographic features of 6-11 km, typical of Saturn icy satellites with similar size and density. We constrain Chariklo's geometric albedo between 3.1% (sphere) and 4.9% (ellipsoid), while the ring I/F reflectivity is less constrained between 0.6% (Jacobi) and 8.9% (sphere). The ellipsoid model explains both the optical light curve and the long-term photometry variation of the system, giving a plausible value for the geometric albedo of the ring particles of $10 - 15\%$. The derived Chariklo's mass of 6-8$\times 10^{18}$ kg places the rings close to the 3:1 resonance between the ring mean motion and Chariklo's rotation period.

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Preprints available on the web at `https://arxiv.org/abs/1708.08934`
and `https://doi.org/10.3847/1538-3881/aa8956`

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"TNOs are Cool": A Survey of the Trans-Neptunian Region XIII. Statistical Analysis of Multiple Trans-Neptunian Objects Observed with Herschel Space Observatory

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Context. Gravitationally bound multiple systems provide an opportunity to estimate the mean bulk density of the objects, whereas this characteristic is not available for single objects. Being a primitive population of the outer Solar System, binary and multiple trans-Neptunian objects (TNOs) provide unique information about bulk density and internal structure, improving our understanding of their formation and evolution.

Aims. The goal of this work is to analyse parameters of multiple trans-Neptunian systems, observed with Herschel and Spitzer space telescopes. Particularly, statistical analysis is done for radiometric size and geometric albedo, obtained from photometric observations, and for estimated bulk density.

Methods. We use Monte Carlo simulation to estimate the real size distribution of TNOs. For this purpose, we expand the dataset of diameters by adopting the Minor Planet Center database list with available values of the absolute magnitude therein, and the albedo distribution derived from Herschel radiometric measurements. We use the 2-sample Anderson-Darling non-parametric statistical method for testing whether two samples of diameters, for binary and single TNOs, come from the same distribution. Additionally, we use the Spearman's coefficient as a measure of rank correlations between parameters. Uncertainties of estimated parameters together with lack of data are taken into account. Conclusions about correlations between parameters are based on statistical hypothesis testing.

Results. We have found that the difference in size distributions of multiple and single TNOs is biased by small objects. The test on correlations between parameters shows that the effective diameter of binary TNOs strongly correlates with heliocentric orbital inclination and with magnitude difference between components of binary system. The correlation between diameter and magnitude difference implies that small and large binaries are formed by different mechanisms. Furthermore, the statistical test indicates, although not significant with the sample size, that a moderately strong correlation exists between diameter and bulk density.

To appear in: Astronomy and Astrophysics
For preprints, contact irina.kovalenko@iki.rssi.ru
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Taxonomy of TNOs and Centaurs as Seen From Spectroscopy

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Taxonomy of Trans-Neptunian Objects (TNOs) and Centaurs has been made in previous works using broadband filters in the visible and near infrared ranges. This initial investigation led to the

establishment of four groups with the aim to provide the mean colors of the different classes with possible links with any physical or chemical properties. However, this taxonomy was only made with the Johnson-Cousins filter system and the ESO J, H, Ks filters combination, and any association with other filter system is not yet available. We aim to edit complete visible to near infrared taxonomy and extend this work to any possible filters system. To do this, we generate mean spectra for each individual group, from a data set of 43 spectra. This work also presents new spectra of the TNO (38628) Huya, on which aqueous alteration has been suspected, and the Centaur 2007 VH_{305}. To generate the mean spectra for each taxonomical group, we first averaged the data for each of the four taxonomical groups and checked that spectroscopic and photometric data were consistent according to their relative errors. We obtained four complete spectra corresponding to the different classes from 0.45 to 2.40 microns. Our results based on spectroscopy are in good agreements with those obtained in photometry for the bluest (BB) and reddest (RR) objects. At the contrary, no clear patterns appear for the two intermediate groups (BR and IR). Both BR and IR mean-spectra are almost intermixed, probably due to the fact that part of these objects have not always clear affiliation to one particular taxonomical group. We provide mean spectra that could be used to edit colors in different filters system working in this wavelength range. This work clearly establish the mean spectra of the BB and RR group while the two other groups need probably further refinement.

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The Thermal Emission of Centaurs and Trans-Neptunian Objects at Millimeter Wavelengths from ALMA Observations

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The sensitivity of ALMA makes it possible to detect thermal mm/submm emission from small and/or distant solar system bodies at the sub-mJy level. While the measured fluxes are primarily sensitive to the objects' diameters, deriving precise sizes is somewhat hampered by the uncertain effective emissivity at these wavelengths. Following recent work presenting ALMA data for four trans-Neptunian objects (TNOs) with satellites, we report on ALMA 233 GHz (1.29 mm) flux measurements of four Centaurs (2002 GZ_{32}, Bienor, Chiron, Chariklo) and two other TNOs (Huya and Makemake), sampling a range of sizes, albedos, and compositions. These thermal fluxes are combined with previously published fluxes in the mid/far infrared in order to derive their relative emissivity at radio (mm/submm) wavelengths, using the Near Earth Asteroid Standard Model (NEATM) and thermophysical models. We reassess earlier thermal measurements of these and other objects – including Pluto/Charon and Varuna – exploring, in particular, effects due to non-spherical shape and varying apparent pole orientation whenever information is available, and show that these effects can be key for reconciling previous diameter determinations and correctly estimating the spectral emissivities. We also evaluate the possible contribution to thermal fluxes of established (Chariklo) or claimed (Chiron) ring systems. For Chariklo, the rings do not impact the diameter determinations by more than ∼5%; for Chiron, invoking a ring system does not help in improving the consistency between the numerous past size measurements. As a general conclusion, all the objects, except Makemake, have radio emissivities significantly lower than unity. Although the emissivity values show diversity, we do not find any significant trend with physical parameters such as diameter, composition, beaming factor, albedo, or color, but we suggest that the emissivity could be correlated with grain size. The mean relative radio emissivity is found to be 0.70±0.13, a value that we recommend for the analysis of further mm/submm data.

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For preprints, contact emmanuel.lellouch@obspm.fr
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Was Planet 9 Captured in the Sun's Natal Star-forming Region?

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The presence of an unseen 'Planet 9' on the outskirts of the Solar system has been invoked to explain the unexpected clustering of the orbits of several Edgeworth–Kuiper Belt Objects. We use N-body simulations to investigate the probability that Planet 9 was a free-floating planet (FFLOP) that was captured by the Sun in its birth star-formation environment. We find that only 1-6% of FFLOPs are ensnared by stars, even with the most optimal initial conditions for capture in star-forming regions (one FFLOP per star, and highly correlated stellar velocities to facilitate capture). Depending on the initial conditions of the star-forming regions, only 5-10 of 10 000 planets are captured onto orbits that lie within the constraints for Planet 9. When we apply an additional environmental constraint for Solar system formation – namely the injection of short-lived radioisotopes into the Sun's protoplanetary disc from supernovae – we find the probability for the capture of Planet 9 to be almost zero.

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Details of Resonant Structures Within a Nice Model Kuiper Belt: Predictions for High-Perihelion TNO Detections

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We analyze a detailed Nice model simulation of Kuiper Belt emplacement from Brasser & Morbidelli 2013, where Neptune undergoes a high eccentricity phase and migrates outward. In this work, which follows from Pike et al. 2017, we specifically focus on the details of structures within Neptune's mean motion resonances and in the high pericenter population of simulated trans-Neptunian Objects (TNOs). We find several characteristics of these populations which should be observable in the distant Solar System in future large-scale TNO surveys as a diagnostic of whether or not this mode of Neptune migration occurred in the early Solar System. We find that the leading asymmetric libration islands of the n:1 resonances are generally much more populated than the trailing islands. We also find the non-resonant high-q population of TNOs should have higher inclinations than the low-q population due to the importance of Kozai cycling during their emplacement histories. Finally, high-q TNOs should be present in roughly equal numbers on either side of distant mean-motion resonances. These predictions contrast with predictions from other Kuiper Belt emplacement simulations, and will be testable by upcoming surveys.

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Binary Stripping as a Plausible Origin of Correlated Pairs of Extreme Trans-Neptunian Objects

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Asteroids that follow similar orbits may have a dynamical connection as their current paths could be the result of a past interaction with a massive perturber. The pair of extreme trans-Neptunian objects or ETNOs (474640) 2004 VN_{112}–2013 RF_{98} exhibits peculiar relative orbital properties, including a difference in longitude of the ascending node of just 1.61° and 3.99° in inclination. In addition, their reflectance spectra are similar in the visible portion of the spectrum. The origin of these similarities remains unclear. Neglecting observational bias, viable scenarios that could explain this level of coincidence include fragmentation and binary dissociation. Here, we present results of extensive direct N-body simulations of close encounters between wide binary ETNOs and one trans-Plutonian planet. We find that wide binary ETNOs can dissociate during such interactions and the relative orbital properties of the resulting unbound couples match reasonably well those of several pairs of known ETNOs, including 474640–2013 RF_{98}. The possible presence of former binaries among the known ETNOs has strong implications for the interpretation of the observed anisotropies in the distributions of the directions of their orbital poles and perihelia.

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OTHER PAPERS OF INTEREST

The HIP 79977 Debris Disk in Polarized Light

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We present observations of the known edge-on debris disk around HIP 79977 (HD 146897, F star in Upper Sco, 123 pc), taken with the ZIMPOL differential polarimeter of the SPHERE instrument in the Very Broad Band filter (λ_c = 735 nm, $\Delta\lambda$ = 290 nm) with a spatial resolution of about 25 mas. We measure the polarization flux along and perpendicular to the disk spine of the highly inclined disk for projected separations between 0.2" (25 AU) and 1.6" (200 AU) and investigate the diagnostic potential of such data with model simulations. The polarized flux contrast ratio for the disk is $F_{pol}/F_* = (5.5 \pm 0.9)10^{-4}$. The surface brightness reaches a maximum of 16.2 mag arcsec^{-2} at a separation of $0.2'' - 0.5''$ along the disk spine with a maximum surface brightness contrast of 7.64 mag arcsec^{-2}. The polarized flux has a minimum near the star $< 0.2''$ because no or only little polarization is produced by forward or backward scattering in the disk section lying in front of or behind the star. The data are modeled as a circular dust belt with an inclination $i = 85(\pm 1.5)^\circ$ and a radius between $r_0 = 60$ AU and 90 AU. The radial density dependence is described by $(r/r_0)^\alpha$ with a steep power law index $\alpha = 5$ inside r_0 and a more shallow index $\alpha = -2.5$ outside r_0. The scattering asymmetry factor lies between $g = 0.2$ and 0.6 adopting a scattering angle-dependence for the fractional polarization such as that for Rayleigh scattering. Our data are qualitatively very similar to the case of AU Mic and they confirm that edge-on debris disks have a polarization minimum at a position near the star and a maximum near the projected separation of the main debris belt. The comparison of the polarized flux contrast ratio F_{pol}/F_* with the fractional infrared excess provides strong constraints on the scattering albedo of the dust.

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