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DISTANT EKOs

The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

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NEWS & ANNOUNCEMENTS

There were no new TNO/Centaur/SDO discoveries announced since the previous issue of *Distant EKOs*.

Deleted/Re-identified objects:

2003 UW292 = 2005 UN524

Current number of TNOs: 1093 (including Pluto)
Current number of Centaurs/SDOs: 243
Current number of Neptune Trojans: 6

Out of a total of 1342 objects:
548 have measurements from only one opposition
538 of those have had no measurements for more than a year
288 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

Herschel Open Time Key Programme: TNOs are Cool: A Survey of the Transneptunian Region

Thomas G. Müller[1], **Emmanuel Lellouch**[2], **Hermann Böhnhardt**[3], **John Stansberry**[4], **Antonella Barucci**[2], **Jacques Crovisier**[2], **Audrey Delsanti**[2], **Alain Doressoundiram**[2], **Elisabetta Dotto**[5], **René Duffard**[6], **Sonia Fornasier**[2], **Olivier Groussin**[7], **Pedro J. Gutiérrez**[6], **Olivier Hainaut**[8], **Alan W. Harris**[9], **Paul Hartogh**[3], **Daniel Hestroffer**[10], **Jonathan Horner**[11], **Dave Jewitt**[12], **Mark Kidger**[13], **Csaba Kiss**[14], **Pedro Lacerda**[15], **Luisa Lara**[6], **Tanya Lim**[16], **Michael Mueller**[4], **Raphael Moreno**[2], **Jose-Luis Ortiz**[6], **Silvia Protopapa**[3], **Miriam Rengel**[3], **Pablo Santos-Sanz**[6], **Bruce Swinyard**[16], **Nicolas Thomas**[17], **Audrey Thirouin**[6], and **David Trilling**[18]

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Over one thousand objects have so far been discovered orbiting beyond Neptune. These trans-Neptunian objects (TNOs) represent the primitive remnants of the planetesimal disk from which the planets formed and are perhaps analogous to the unseen dust parent-bodies in debris disks observed around other main-sequence stars. The dynamical and physical properties of these bodies provide unique and important constraints on formation and evolution models of the Solar System. While the dynamical architecture in this region (also known as the Kuiper Belt) is becoming relatively clear, the physical properties of the objects are still largely unexplored. In particular, fundamental parameters such as size, albedo, density and thermal properties are difficult to measure. Measurements of thermal emission, which peaks at far-IR wavelengths, offer the best means available to determine the physical properties. While *Spitzer* has provided some results, notably revealing a large albedo diversity in this population, the increased sensitivity of *Herschel* and its superior wavelength coverage should permit profound advances in the field.

Within our accepted project we propose to perform radiometric measurements of 139 objects, including 25 known multiple systems. When combined with measurements of the dust population beyond Neptune (e.g. from the New Horizons mission to Pluto), our results will provide a benchmark for understanding the Solar debris disk, and extra-solar ones as well.

To appear in: Earth, Moon and Planets, Issue 105 (2009 August)
For preprints, contact `tmueller@mpe.mpg.de`

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The History of the Solar System's Debris Disc: Observable Properties of the Kuiper Belt

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The Nice model of Gomes et al. suggests that the migration of the giant planets caused a planetesimal clearing event which led to the Late Heavy Bombardment (LHB) at 880 Myr. Here we investigate the IR emission from the Kuiper belt during the history of the Solar System as described by the Nice model. We describe a method for easily converting the results of N-body planetesimal simulations into observational properties (assuming black-body grains and a single size distribution) and further modify this method to improve its realism (using realistic grain properties and a three-phase size distribution). We compare our results with observed debris discs and evaluate the plausibility of detecting an LHB-like process in extrasolar systems. Recent surveys have shown that 4% of stars exhibit 24 μm excess and 16% exhibit 70 μm excess. We show that the Solar System would have been amongst the brightest of these systems before the LHB at both 24 and 70 μm. We find a significant increase in 24 μm emission during the LHB, which rapidly drops off and becomes undetectable within 30 Myr, whereas the 70 μm emission remains detectable until 360 Myr after the LHB. Comparison with the statistics of debris disc evolution shows that such depletion events must be rare occurring around less than 12% of Sun-like stars and with this level of incidence we would expect approximately one of the 413 Sun-like, field stars so far detected to have a 24 μm excess to be currently going through an LHB. We also find that collisional processes are important in the Solar System before the LHB and that parameters for weak Kuiper belt objects are inconsistent with the Nice model interpretation of the LHB.

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For preprints, contact `mbooth@ast.cam.ac.uk`

or on the web at `http://uk.arxiv.org/abs/0906.3755`

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Trans-Neptunian Region Architecture: Evidence for a Planet Beyond Pluto

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Trans-Neptunian objects (TNOs) orbiting in the Edgeworth-Kuiper Belt carry precious information about the origin and evolution of the Solar System. The Kuiper Belt has a very complex orbital structure. Indeed, TNOs exhibit surprisingly large eccentricities, e, and inclinations, i, and are classified in distinct dynamical classes. Here we propose that the Kuiper Belt orbital structure can be explained by a massive scattered planetesimal with tenths of the Earth's mass, which later remained in the system in a distant stable orbit (an outer planet). Near the end of planet formation,

the outer planet was firstly scattered by one of the icy giant planets, then it dynamically excited the primordial planetesimal disk over at least tens of Myr, reproducing the levels observed at 40–50 AU and the truncation of the disk at about 48 AU before planet migration. Later, the outer planet was captured by a distant resonance with Neptune of the type r:1 or r:2 (e.g., 6:1, 7:1, ...), acquiring an inclined stable orbit (=100 AU; 20–40°), thus preserving the Kuiper Belt over ∼4 Gyr. Our model explains the following: 1) Depletion of the inner Kuiper Belt; 2) The entire currently known resonant populations in the Kuiper Belt, including Neptune Trojans and resonant TNOs in distant resonances (> 50 AU); 3) Formation of scattered and detached TNOs, including analogues of (136199) Eris, 2004 XR190, (148209) 2000 CR105, and (90377) Sedna; 4) Classical TNOs and their dual nature of cold and hot populations; 5) Orbital excitation of classical TNOs; 6) The Kuiper Belt outer edge at about 48 AU; 7) Loss of ∼99% of the initial total mass of the Kuiper Belt through dynamical depletion and enhanced collisional grinding; 8) Neptune's current orbit at 30.1 AU. In summary, our scenario consistently reproduces all main aspects of Kuiper Belt architecture with unprecedented detail. The best constraints obtained from the model for the outer planet are: $a_P = 100 - 175$ AU (currently near or inside an r:1 or r:2 resonance), $q_P > 80$ AU, $i_P = 20° - 40°$, and apparent magnitude $m_P \sim 15 - 17$ mag at perihelion (assuming an albedo of 0.1–0.3 and $q_P = 80 - 90$ AU).

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For preprints, contact `patryksan@gmail.com`
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Kozai Cycles, Tidal Friction, and the Dynamical Evolution of Binary Minor Planets

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In recent years, many binary minor planets (BMPs) have been discovered in the solar system. Many models have been suggested for their formation, but these encounter difficulties explaining their observed characteristics. Here, we show that secular perturbations by the Sun (Kozai mechanism) fundamentally change the evolution and the initial distribution of BMPs predicted by such models and lead to unique observational signatures. The Kozai mechanism can lead to a large periodic oscillations in the eccentricity and inclination of highly inclined BMP orbits, where we predict such effects to be observable with current accuracy within a few years (e.g., for the binary asteroid Huenna). In addition, the combined effects of the Kozai mechanism and tidal friction (KCTF) drives BMPs into short-period circular orbits. We predict a specific inclination-dependent distribution of the separation and eccentricity of BMPs, due to these effects, including a zone of avoidance at the highest inclinations. Specifically, the Kozai evolution could explain the recently observed peculiar orbit of the Kuiper Belt binary 2001 QW322. Additionally, the KCTF process could lead to BMPs coalescence and serve as an important route for the formation of irregular shaped single minor planets with large axial tilts.

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Preprints available on the web at `http://arxiv.org/abs/0809.2095`

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Formation of the Resonant Populations in the Kuiper Belt: Gas-drag-induced Resonant Capture

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On the basis of their orbital elements, present-day Kuiper belt objects can be grouped into distinct dynamical classes: classical, resonant and scattered ones. Jiang and Yeh have proposed gas-drag-induced resonant capture in a protostellar disc analogous to the primordial solar nebula as a mechanism able to explain the dominant 3:2 resonant population observed in Kuiper belt objects. de la Fuente Marcos and de la Fuente Marcos further investigated the drag-induced mechanism numerically. Our significant contribution is a hydrodynamic theory derivation of results obtained in the Jiang and Yeh, and de la Fuente Marcos and de la Fuente Marcos numerical simulations.

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Two Dynamical Classes of Centaurs

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The Centaurs are a transient population of small bodies in the outer solar system whose orbits are strongly chaotic. These objects typically suffer significant changes of orbital parameters on timescales of a few thousand years, and their orbital evolution exhibits two types of behaviors described qualitatively as random-walk and resonance-sticking. We have analyzed the chaotic behavior of the known Centaurs. Our analysis has revealed that the two types of chaotic evolution are quantitatively distinguishable: (1) the random walk-type behavior is well described by so-called generalized diffusion in which the rms deviation of the semimajor axis grows with time t as $\sim t^H$, with *Hurst* exponent H in the range 0.22–0.95, however (2) orbital evolution dominated by intermittent resonance sticking, with sudden jumps from one mean motion resonance to another, has poorly defined H. We further find that these two types of behavior are correlated with Centaur dynamical lifetime: most Centaurs whose dynamical lifetime is less than ∼22 Myr exhibit generalized diffusion, whereas most Centaurs of longer dynamical lifetimes exhibit intermittent resonance sticking. We also find that Centaurs in the diffusing class are likely to evolve into Jupiter-family comets during their dynamical lifetimes, while those in the resonance-hopping class do not.

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or on the web at http://arxiv.org/abs/0906.4795

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Origin and Dynamical Evolution of Neptune Trojans – I: Formation and Planetary Migration

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We present the results of detailed dynamical simulations of the effect of the migration of the four giant planets on both the transport of pre-formed Neptune Trojans, and the capture of new Trojans from a trans-Neptunian disk. The cloud of pre-formed Trojans consisted of thousands of massless particles placed on dynamically cold orbits around Neptune's L4 and L5 Lagrange points, while the trans-Neptunian disk contained tens of thousands of such particles spread on dynamically cold orbits between the initial and final locations of Neptune. Through comparison of the results with previous work on the known Neptunian Trojans, we find that scenarios involving the slow migration of Neptune over a large distance (50 Myr to migrate from 18.1 AU to its current location, using an exponential-folding time of $t = 10$ Myr) provide the best match to the properties of the known Trojans. Scenarios with faster migration (5 Myr, with $t = 1$ Myr), and those in which Neptune migrates from 23.1 AU to its current location, fail to adequately reproduce the current day Trojan population. Scenarios which avoid disruptive perturbation events between Uranus and Neptune fail to yield any significant excitation of pre-formed Trojans (transported with efficiencies between 30% and 98% whilst maintaining the dynamically cold nature of these objects – $e < 0.1$, $i < 5°$). Conversely, scenarios with periods of strong Uranus-Neptune perturbation lead to the almost complete loss of such pre-formed objects. In these cases, a small fraction (∼0.15%) of these escaped objects are later recaptured as Trojans prior to the end of migration, with a wide range of eccentricities (< 0.35) and inclinations ($< 40°$). In all scenarios (including those with such disruptive interaction between Uranus and Neptune) the capture of objects from the trans-Neptunian disk (through which Neptune migrates) is achieved with efficiencies between ∼0.1% and ∼1%. The captured Trojans display a wide range of inclinations ($< 40°$ for slow migration, and $< 20\circ$ for rapid migration) and eccentricities (< 0.35), and we conclude that, given the vast amount of material which undoubtedly formed beyond the orbit of Neptune, such captured objects may be sufficient to explain the entire Neptune Trojan population.

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The Dynamics of Neptune Trojan: I. The Inclined Orbits

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The stability of Trojan type orbits around Neptune is studied. As the first part of our investigation, we present in this paper a global view of the stability of Trojans on inclined orbits. Using the frequency analysis method based on the FFT technique, we construct high resolution dynamical maps on the plane of initial semimajor axis a_0 versus inclination i_0. These maps show three most stable regions, with i_0 in the range of $(0°, 12°), (22°, 36°)$ and $(51°, 59°)$ respectively, where the

Trojans are most probably expected to be found. The similarity between the maps for the leading and trailing triangular Lagrange points L_4 and L_5 confirms the dynamical symmetry between these two points. By computing the power spectrum and the proper frequencies of the Trojan motion, we figure out the mechanisms that trigger chaos in the motion. The Kozai resonance found at high inclination varies the eccentricity and inclination of orbits, while the ν_8 secular resonance around $i_0 \sim 44^\circ$ pumps up the eccentricity. Both mechanisms lead to eccentric orbits and encounters with Uranus that introduce strong perturbation and drive the objects away from the Trojan like orbits. This explains the clearance of Trojan at high inclination ($> 60^\circ$) and an unstable gap around 44° on the dynamical map. An empirical theory is derived from the numerical results, with which the main secular resonances are located on the initial plane of (a_0, i_0). The fine structures in the dynamical maps can be explained by these secular resonances.

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For preprints, contact zhouly@nju.edu.cn
or on the web at http://arxiv.org/abs/0906.5075

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The Creation of Haumea's Collisional Family

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Recently, the first collisional family was discovered in the Kuiper belt. The parent body of this family, Haumea, is one of the largest objects in the Kuiper belt and is orbited by two satellites. It has been proposed that the Haumea family was created from dispersed fragments that resulted from a giant impact. This proposed origin of the Haumea family is however in conflict with the observed velocity dispersion between the family members (∼140 m/s) which is significantly less than the escape velocity from Haumea's surface (∼900 m/s). In this paper we propose a different formation scenario for Haumea's collisional family. In our scenario the family members are ejected while in orbit around Haumea. This scenario, therefore, gives naturally rise to a lower velocity dispersion among the family members than expected from direct ejection from Haumea's surface. In our scenario Haumea's giant impact forms a single moon that tidally evolves outward until it suffers a destructive collision from which the family is created. We show that this formation scenario yields a velocity dispersion of ∼190 m/s among the family members which is in good agreement with the observations. We discuss an alternative scenario that consists of the formation and tidal evolution of several satellites that are ejected by collisions with unbound Kuiper belt objects. However, the formation of the Haumea family in this latter way is difficult to reconcile with the large abundance of Kuiper belt binaries. We therefore favor forming the family by a destructive collision of a single moon of Haumea. The probability for Haumea's initial giant impact in todays Kuiper belt is less than 10^{-3}. In our scenario, however, Haumea's giant impact can occur before the excitation of the Kuiper belt and the ejection of the family members afterwards. This has the advantage that one can preserve the dynamical coherence of the family and explain Haumea's original giant impact, which is several orders of magnitude more likely to have occurred in the primordial dynamically cold Kuiper belt compared to the dynamically excited Kuiper belt today.

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Can Collisional Activity Produce a Crystallization of Edgeworth-Kuiper Belt Comets?

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Kuiper Belt Objects and cometary nuclei are considered among the most pristine bodies of the outer solar system. However, the composition of these objects might not reflect that of the planetesimals from which they accreted. They have experienced some collisional activity since the formation of the Edgeworth-Kuiper Belt, leading to a possible alteration of their structure and composition. Here, we examine the possible alteration of icy bodies (10 to 100 km radii) located in the primitive Edgeworth-Kuiper Belt due to the heat generated by collisions of planetesimals with sizes not exceeding 10% of the target body. We use a cometary nucleus model initially made of a mixture of amorphous ice and dust to investigate the influence of the target's intrinsic properties on its post-impact thermodynamical evolution. We show that multiple collisions must be considered over long periods to trigger a continuous crystallization within a target owning a typical cometary composition. However, the collision rates we have determined are approximately 1000 times greater than those predicted for the current collisional environment in the Edgeworth-Kuiper Belt. This implies that the collisional processes that occurred over the age of the Solar System did not produce any phase transition of H_2O ice from amorphous to crystalline form in cometary size bodies located in the primitive Edgeworth-Kuiper Belt.

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Thermal Evolution of Kuiper Belt Objects, With Implications For Cryovolcanism

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We investigate the internal thermal evolution of Kuiper belt objects (KBOs), small (radii < 1000 km), icy (mean densities < 2500 kg m^{-3}) bodies orbiting beyond Neptune, focusing on Pluto's moon Charon in particular. Our calculations are time-dependent and account for differentiation. We review evidence for ammonia hydrates in the ices of KBOs, and include their effects on the thermal evolution. A key finding is that the production of the first melt, at the melting point of ammonia dihydrate, $\approx$176 K, triggers differentiation of rock and ice. The resulting structure comprises a rocky core surrounded by liquids and ice, enclosed within a > 100 km thick undifferentiated crust of rock and ice. This structure is especially conducive to the retention of subsurface liquid, and bodies the size of Charon or larger (radii > 600 km) are predicted to retain some subsurface liquid to the present day. We discuss the possibility that this liquid can be brought to the surface rapidly via self-propagating cracks. We conclude that cryovolcanism is a viable process expected to affect the surfaces of large KBOs including Charon.

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ESO Large Program about TNOs: Surface variations on (47171) 1999 TC_{36}

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Aims. We investigate the surface composition of the Plutino (47171) 1999 TC_{36}.

Methods. We completed near-infrared photometric and spectroscopic observations of (47171) 1999 TC_{36} with the adaptive optics instrument NACO at the ESO VLT during 12 October 2006, and present these data with ISAAC and SINFONI spectroscopic observations carried out about one month later on 9 November 2006 and 8 November 2006, respectively. The ISAAC and SINFONI spectroscopic observations were combined with a visible spectrum obtained by FORS1 on 9 November 2006. Composition and properties of the compounds present on the surface of the target are investigated by applying a Hapke radiative transfer model to the measured spectra and to previously published observations.

Results. We present the relative reflectance spectrum of (47171) 1999 TC_{36} in the wavelength range (0.37-2.33) μm. An intimate mixture of Triton tholin, Titan tholin, serpentine, and Triton tholin diluted in water ice represents the best-fit model description of the measured spectrum. Any significant differences from the published spectra of (47171) 1999 TC_{36} taken on 2001 and 2003 could be due to surface heterogeneity.

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Composition of KBO (50000) Quaoar

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Aims. The objective of this work is to investigate the physical properties of objects beyond Neptune — the new frontiers of the Solar System — and in particular to study the surface composition of (50000) Quaoar, a classical Transneptunian (or Kuiper Belt) object. Because of its distance from the Sun, Quaoar is expected to have preserved, to a degree, its original composition. Our goals are to determine to what degree this is true and to shed light on the chemical evolution of this icy body.

Methods. We present new near-infrared (3.6 and 4.5 μm) photometric data obtained with the Spitzer Space Telescope. These data complement high resolution, low signal-to-noise spectroscopic and photometric data obtained in the visible and near-infrared (0.4–2.3 μm) at VLT-ESO and provide an excellent set of constraints in the model calculation process. We perform spectral modeling of the

entire wavelength range — from 0.3 to 4.5 μm by means of a code based on the Shkuratov radiative transfer formulation of the slab model. We also attempt to determine the temperature of H_2O ice making use of the crystalline feature at 1.65 μm.

Results. We present a model confirming previous results regarding the presence of crystalline H_2O and CH_4 ice, as well as C_2H_6 and organic materials, on the surface of this distant icy body. We attempt a measurement of the temperature and find that stronger constraints on the composition are needed to obtain a precise determination.

Conclusions. Model fits indicate that N_2 may be a significant component, along with a component that is bright at $\lambda > 3.3$ μm, which we suggest at this time could be amorphous H_2O ice in tiny grains or thin grain coatings. Irradiated crystalline H_2O could be the source of small-grained amorphous H_2O ice. The albedo and composition of Quaoar, in particular the presence of N_2, if confirmed, make this TNO quite similar to Triton and Pluto.

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The Rotation Period and Light-Curve Amplitude of Kuiper Belt Dwarf Planet 136472 Makemake (2005 FY9)

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Kuiper Belt dwarf planet 136472 Makemake, formerly known as 2005 FY9, is currently the third-largest known object in the Kuiper Belt, after the dwarf planets Pluto and Eris. It is currently second only to Pluto in apparent brightness, due to Eris' much larger heliocentric distance. Makemake shows very little photometric variability, which has prevented confident determination of its rotation period until now. Using extremely precise time-series photometry, we find that the rotation period of Makemake is 7.7710 ± 0.0030 hr, where the uncertainty is a 90% confidence interval. An alias period is detected at 11.41 hr, but is determined with approximately 95% confidence not to be the true period. Makemake's 7.77 hr rotation period is in the typical range for Kuiper Belt objects, consistent with Makemake's apparent lack of a substantial satellite to alter its rotation through tides. The amplitude of Makemake's photometric light curve is 0.0286 ± 0.0016 mag in V. This amplitude is about 10 times less than Pluto's, which is surprising given the two objects' similar sizes and spectral characteristics. Makemake's photometric variability is instead similar to that of Eris, which is so small that no confident rotation period has yet been determined. It has been suggested that dwarf planets such as Makemake and Eris, both farther from the Sun and colder than Pluto, exhibit lower photometric variability because they are covered with a uniform layer of frost. Such a frost is probably the correct explanation for Eris. However, it may be inconsistent with the spectrum of Makemake, which resembles reddish Pluto more than neutrally colored Eris. Makemake may instead be a more Pluto-like object that we observe at present with a nearly pole-on viewing geometry — a possibility that can be tested with continuing observations over the coming decades.

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A Search for Occultations of Bright Stars by Small Kuiper Belt Objects Using Megacam on the MMT

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We conducted a search for occultations of bright stars by Kuiper Belt Objects (KBOs) to estimate the density of sub-km KBOs in the sky. We report here the first results of this occultation survey of the outer solar system conducted in 2007 June and 2008 June/July at the MMT Observatory using Megacam, the large MMT optical imager. We used Megacam in a novel shutterless *continuous–readout* mode to achieve high precision photometry at 200 Hz, which with point-spread function convolution results in an effective sampling of ~ 30 Hz. We present an analysis of 220 star hours at signal-to-noise ratio of 25 or greater, taken from images of fields within 3° of the ecliptic plane. The survey efficiency is greater than 10% for occultations by KBOs of diameter $d \geq 0.7$ km, and we report no detections in our data set. We set a new 95% confidence level upper limit for the surface density $\Sigma_N(d)$ of KBOs larger than 1 km: $\Sigma_N(d \geq 1\ \mathrm{km}) \leq 2.0 \times 10^8\ \mathrm{deg}^{-2}$, and for KBOs larger than 0.7 km $\Sigma_\mathrm{N}(\mathrm{d} \geq 0.7\ \mathrm{km}) \leq 4.8 \times 10^8\ \mathrm{deg}^{-2}$.

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Buoyancy Waves in Pluto's High Atmosphere: Implications for Stellar Occultations

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We apply scintillation theory to stellar signal fluctuations in the high-resolution, high signal/noise, dual-wavelength data from the MMT observation of the 2007 March 18 occultation of P445.3 by Pluto. A well-defined high wavenumber cutoff in the fluctuations is consistent with viscous-thermal dissipation of buoyancy waves (internal gravity waves) in Plutos high atmosphere, and provides strong evidence that the underlying density fluctuations are governed by the gravity-wave dispersion relation.

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THESES

Orbital Dynamics of Kuiper Belt Object Satellites, A Kuiper Belt Family, and Extra-Solar Planet Interiors

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This thesis discusses research into four different orbital dynamics problems, where the main goal of each chapter is to characterize the strongest non-Keplerian effect. These problems are introduced and discussed in Chapter 1, to help provide context for the subsequent chapters. In Chapter 2, I discuss a new technique for probing the interior density distributions of extra-solar planets by observing apsidal precession. Using a detailed theoretical and observational model of this precession, I conclude that NASA's Kepler mission will be able to detect the presence or absence of a massive core in very hot Jupiters with eccentricities greater than 0.003. The remaining chapters discuss the orbital dynamics of Kuiper belt objects (KBOs) orbiting the Sun beyond Neptune. The family of dwarf planet Haumea (2003 EL61) is characterized in Chapter 3, including a list of candidate family members sorted by dynamical proximity. Using a numerical integration of resonance diffusion, I also show that the Haumea family is at least 1 Gyr old and is probably primordial. In Chapter 4, I analyze and fit astrometric data for the two satellites of Haumea (Hi'iaka and Namaka) to determine their orbital properties and the masses of Haumea and Hi'iaka. The implications of the new orbital solution are discussed, including the exciting conclusion that Haumea and Namaka are currently starting a season of mutual events. A more general investigation of the orbital and tidal evolution of KBO binaries is given in Chapter 5. A new orbital evolution model is described that accounts for perturbations from the Sun, self-consistent tidal evolution, and non-hydrostatic quadrupoles of solid KBOs. Using this model, I find that the orbital parameters of KBO binaries may have been modified significantly over the age of the solar system. Applied to the Orcus-Vanth binary, this model shows that a short-period circular orbit does not necessarily imply a collisional formation. In all, the work in this thesis has sought to analyze observational data by using the theoretical tools of orbital dynamics.

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Entire thesis available on the web at
`http://etd.caltech.edu/etd/available/etd-05282009-164537/`

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