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DISTANT EKOs

The Kuiper Belt Electronic Newsletter

Edited by: Joel Wm. Parker

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NEWS & ANNOUNCEMENTS

10...9...8...7...6...5...4...3...2...1...Liftoff!

New Horizons launched at 19:00 UT on Thursday, January 19, 2006. After a launch slip from the original date of January 11th and a few delays due to weather, the launch went beautifully. All three rocket stages performed as expected, and now the New Horizons spacecraft is on course to Pluto and the Kuiper belt. Flyby of Pluto is on July 14th, 2015. In an interesting coincidence that gives one perspective on the timescale of solar system exploration progress, the Pluto flyby will be on the 50th anniversary of the Mars flyby of Mariner 4, the first spacecraft to obtain and transmit close range images of Mars.
For more videos and information about the New Horizons launch, and to keep up with news on the mission, see the website at at: `http://pluto.jhuapl.edu/`

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Another Centaur shows cometary activity. In IAUC 8656, Choi and Weissman report detection of a coma around 2000 EC98. Broadband images show a coma extending about 20 arcsec from the nucleus.
IAUC 8656: `http://cfa-www.harvard.edu/iauc/08600/08656.html`

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Three more Neptunian trojans (2005 TN53, 2005 TN74, and 2005 TO74) were found by Sheppard and Trujillo, bringing the total to five.

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There were 14 new TNO discoveries announced since the previous issue of *Distant EKOs*:

2004 UW10, 2002 PA171, 2002 PB171, 2002 PC171, 2002 PR170, 2002 PS170, 2002 PT170, 2002 PU170, 2002 PV170, 2002 PW170, 2002 PX170, 2002 PY170, 2002 PZ170, 2003 MW12

6 new Centaur/SDO discoveries:

2004 XQ190, 2005 TH173, 1999 TZ1, 2005 UJ438, 2005 VJ119, 2004 XR190

and 2 new Neptunian Trojan discoveries:

2005 TN53, 2005 TO74 (and 2005 TN74, which was previously listed as a TNO)

Objects recently assigned numbers:

1996 TQ66 = (118228)
1999 HT11 = (118378)
1999 HC12 = (118379)
2000 OY51 = (118698)
2000 OM67 = (118702)
2001 KJ76 = (119066)
2001 KP76 = (119067)
2001 KC77 = (119068)
2001 KN77 = (119069)
2001 KP77 = (119070)
2001 SQ73 = (119315)
2001 UO18 = (119473)
2002 CY224 = (119878)
2002 KX14 = (119951)
2002 PA149 = (119956)
2002 VR130 = (119976)
2002 WC19 = (119979)
2003 CO1 = (120061)
2003 FY128 = (120132)
2003 OP32 = (120178)
2003 UR292 = (120181)
2004 EW95 = (120216)
2004 SB60 = (120347)
2004 TY364 = (120348)

Objects recently assigned names:

2002 GB10 = Amycus
2002 GO9 = Crantor

Reclassified objects:

- 2005 PT21 (TNO → SDO)
- 2005 PQ21 (TNO → SDO)
- 2005 TN74 (TNO → NTrojan)

Deleted/Re-identified objects:

- 2003 UA118 = 2005 UJ438
- 2001 QG331 = 2002 PM149 = 2005 PQ21

Current number of TNOs: 922 (and Pluto+Charon+P1+P2, and 15 other TNO satellite companions)
Current number of Centaurs/SDOs: 160
Current number of Neptune Trojans: 5

Out of a total of 1087 objects:
496 have measurements from only one opposition
441 of those have had no measurements for more than a year
220 of those have arcs shorter than 10 days
(for more details, see: `http://www.boulder.swri.edu/ekonews/objects/recov_stats.gif`)

PAPERS ACCEPTED TO JOURNALS

The Discovery of Two New Satellites of Pluto

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Pluto's first known moon, Charon, was discovered in 1978 (Christy 1978) and has a diameter about half that of Pluto (Buie 1992,Young 1994, Sicardy 2005), which makes it larger relative to its primary than any other moon in the Solar System. Previous searches for other satellites around Pluto have been unsuccessful (Stern 1991, Stern 1994, Stern 2003), but they were not sensitive to objects $\leq$150 km in diameter and there are no fundamental reasons why Pluto should not have more satellites (Stern 1994). Here we report the discovery of two additional moons around Pluto, provisionally designated S/2005 P1 (hereafter "P1") and S/2005 P2 (hereafter "P2"), which makes Pluto the first Kuiper belt object (KBO) known to have multiple satellites. These new satellites are much smaller than Charon (diameter $\sim$1200 km), with P1 ranging in diameter from 60–165 km depending on the surface reflectivity, and P2 about 20% smaller than P1. Although definitive orbits cannot be derived, both new satellites appear to be moving in circular orbits in the same orbital plane as Charon, with orbital periods of $\sim$38 days (P1) and $\sim$25 days (P2). The implications of the discovery of P1 and P2 for the origin and evolution of the Pluto system, and for the satellite formation process in the Kuiper belt, are discussed in a companion paper (Stern 2006).

To appear in: Nature

Preprints available on the web at http://arxiv.org/abs/astro-ph/0601018

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Characteristics and Origin of the Quadruple System at Pluto

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Our discovery of two new satellites of Pluto, designated S/2005 P1 and S/2005 P2 (henceforth, "P1" and "P2"), combined with the constraints on the absence of more distant satellites of Pluto, reveal that Pluto and its moons comprise an unusual, highly compact, quadruple system. The two newly discovered satellites of Pluto have masses that are small compared to both Pluto and Charon, i.e., between 5×10^{-4} and 1×10^{-5} of Pluto's mass ($M_{\rm pl}$), and between 5×10^{-3} and 1×10^{-4} of Charon's mass. These facts naturally raise the question of how this puzzling satellite system came to be. Here we show that P1 and P2's proximity to Pluto and Charon, along with their apparent locations in high-order mean-motion resonances, likely result from their being constructed from Plutonian collisional ejecta. We argue that variable optical depth dust-ice rings form sporadically in the Pluto system, and that rich satellite systems may be found—perhaps frequently—around other large Kuiper Belt objects.

To appear in: Nature

Preprints available on the web at http://arxiv.org/abs/astro-ph/0512599

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Keck Observatory Laser Guide Star Adaptive Optics Discovery and Characterization of a Satellite to Large Kuiper Belt Object 2003 EL_{61}

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The newly commissioned laser guide star adaptive optics system at Keck Observatory has been used to discover and characterize the orbit of a satellite to the bright Kuiper Belt object 2003 EL_{61}. Observations over a 6 month period show that the satellite has a semimajor axis of $49,500 \pm 400$ km, an orbital period of 49.12 ± 0.03 days, and an eccentricity of 0.050 ± 0.003. The inferred mass of the system is $(4.2 \pm 0.1) \times 10^{21}$ kg, or 32% of the mass of Pluto and $28.6\% \pm 0.7\%$ of the mass of the Pluto-Charon system. Mutual occultations occurred in 1999 and will not occur again until 2138. The orbit is fully consistent neither with one tidally evolved from an earlier closer configuration nor with one evolved inward by dynamical friction from an earlier more distant configuration.

Published in: The Astrophysical Journal Letters, 632, L45 (2005 October 10)

preprints on the web at `www.gps.caltech.edu/~mbrown/papers`

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Near-infrared Color Properties of Kuiper Belt Objects and Centaurs: Final Results from the ESO Large Program*

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**Based on observations collected at the European Southern Observatory, Chile, under program 167.C-0340.*

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We present near-IR JHK broadband photometry for 17 Kuiper Belt Objects (KBOs) and Centaurs. The observations were performed within the ESO Large Program on the "Physical Properties of Kuiper Belt Object and Centaurs" from January 2001 to August 2002. We used the ISAAC instrument at the ESO 8m-Very Large Telescope. We compiled visible / near-IR colors for a total of 51 published objects and performed a statistical analysis. Color-color correlations show that the same coloring process is probably acting on Centaur and KBO surfaces from the visible to the near-IR range.

Centaurs with a $H-K$ smaller than the Sun (0.06) systematically display the reddest $B-V$ colors (at the 2.5σ level). These Centaur surfaces are suspected to harbor material that have spectral signatures around 1.7–2.2μm (water ice is a possibility, it was reported for the three objects that have published spectroscopy). We report no statistically significant evidence for a bimodal structure of the VJHK Centaur colors (Kolmogorov-Smirnoff and dip tests on up to 17 objects). The Centaur $H-K$ colors show some robust evidence (significance level $SL > 99.99\%$) for a continuous structure. We also report a statistically significant bimodal structure of the Centaur $B-R$ distribution, which is compatible with the results published in Peixinho et al (2003) with different data.

Classical KBOs show no trends at the 3σ level. The $V-J$ color is marginally correlated with perihelion distance q (which is consistent with results reported by Doressoundiram et al., 2005, on $B-R$ colors). Resonant and scattered disk objects are under represented (7 and 9 objects respectively) and show no statistically significant trend. Some of the marginal trends are mentioned as worthy of subsequent monitoring.

To appear in: The Astronomical Journal, volume 131 (March 2006)

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Analysis of the Rotational Properties of Kuiper Belt Objects

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We use optical data on 10 Kuiper Belt objects (KBOs) to investigate their rotational properties. Of the 10, three (30%) exhibit light variations with amplitude $\Delta m \geq 0.15$ mag, and 1 out of 10 (10%) has $\Delta m \geq 0.40$ mag, which is in good agreement with previous surveys. These data, in combination with the existing database, are used to discuss the rotational periods, shapes, and densities of Kuiper Belt objects. We find that, in the sampled size range, Kuiper Belt objects have a higher fraction of low amplitude lightcurves and rotate slower than main belt asteroids. The data also show that the rotational properties and the shapes of KBOs depend on size. If we split the database of KBO rotational properties into two size ranges with diameter *larger* and *smaller* than 400 km, we find that: (1) the mean lightcurve amplitudes of the two groups are different with 98.5% confidence, (2) the corresponding power-law shape distributions seem to be different, although the existing data are too sparse to render this difference significant, and (3) the two groups occupy different regions on a *spin period* vs. *lightcurve amplitude* diagram. These differences are interpreted in the context of KBO collisional evolution.

To appear in: The Astronomical Journal

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Short-term Rotational Variability of Eight KBOs from Sierra Nevada Observatory

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In 2001, we started a CCD photometry programme to study the short–term variability of some of the brightest TNOs and Centaurs from the Sierra Nevada observatory. In this paper, we report our latest results on short-term rotational variability of 7 trans-neptunian objects: Orcus (2004 DW), 2002 AW_{197}, 2003 AZ_{84}, 2003 VS_2, 2002 VE_{95}, 2001 YH_{140}, 1996 TL_{66}, and a Centaur: 2003 CO_1. Analysis of the photometric data revealed confident periodicities for 6 objects, with all the lightcurve amplitudes smaller than 0.2 mag, except for 2003 VS_2. Considering all the objects for which reliable lightcurve amplitudes have been reported in the literature (32), the new statistics reveal that 31% of the bodies show variability above 0.15 mag, but only 16% of them display larger amplitudes than 0.4 mag. Here we present a summary of the main results obtained for these objects, and discuss the implications for their basic physical properties.

To appear in: Astronomy and Astrophysics

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Long Term Dynamical Evolution and Classification of Classical TNOs

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Classical trans-Neptunian objects (TNOs) are believed to represent the most dynamically pristine population in the trans-Neptunian belt (TNB) offering unprecedented clues about the formation of our Solar System. The long term dynamical evolution of classical TNOs was investigated using extensive simulations. We followed the evolution of more than 17000 particles with a wide range of initial conditions taking into account the perturbations from the four giant planets for 4 Gyr. The evolution of objects in the classical region is dependent on both their inclination and semimajor axes, with the inner ($a < 45$ AU) and outer regions ($a > 45$ AU) evolving differently. The reason is the influence of overlapping secular resonances with Uranus and Neptune (40–42AU) and the 5:3 ($a \sim 42.3$ AU), 7:4 ($a \sim 43.7$ AU), 9:5 ($a \sim 44.5$ AU) and 11:6 ($a \sim 45.0$ AU) mean motion resonances strongly sculpting the inner region, while in the outer region only the 2:1 mean motion resonance ($a \sim 47.7$ AU) causes important perturbations. In particular, we found: a) A substantial erosion of low-i bodies ($i < 10$ degrees) in the inner region caused by the secular resonances, except those objects that remained protected inside mean motion resonances which survived for billion of years; b) An optimal stable region located at 45 AU$< a <$47 AU, $q > 40$ AU and $i > 5$ degrees free of major perturbations; c) Better defined boundaries for the classical region: 42–47.5 AU ($q > 38$ AU) for cold classical TNOs and 40–47.5 AU ($q > 35$ AU) for hot ones, with $i = 4.5$ degrees as the best threshold to distinguish between both populations; d) The high inclination TNOs seen in the 40–42 AU region reflect their initial conditions. Therefore they should be classified as hot classical TNOs. Lastly, we report a good match between our results and observations, indicating that the former can provide explanations and predictions for the orbital structure in the classical region.

To appear in: Earth, Moon, and Planets
For preprints, contact `patryk@kobe-u.ac.jp`
or on the web at `http://harbor.scitec.kobe-u.ac.jp/~patryk/index-uk.html`

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Exploring the 7:4 Mean Motion Resonance - II: Scattering Evolutionary Paths and Resonance Sticking

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In our preliminary study, we have investigated basic properties and dynamical evolution of classical TNOs around the 7:4 mean motion resonance with Neptune ($a \sim 43.7$ AU), motivated by observational evidences that apparently present irregular features near this resonance (see Lykawka and Mukai, 2005a; hereafter "Paper I"). In this paper, we aim to explore the dynamical long term evolution in the scattered disk (but not its early formation) based on the computer simulations performed in Paper I together with extra computations. Specifically, we integrated the orbital motion of test particles (totalizing a bit more than 10000) placed around the 7:4 mean motion resonance under the effect of the four giant planets for the age of the Solar System. In order to investigate chaotic diffusion, we also conducted a special simulation with on-line computation of proper elements following tracks in phase space over 4–5 Gyr. We found that: (1) A few percent (1–2%) of the test particles survived in the scattered disk with direct influence of other neptunian mean motion resonances, indicating that resonance sticking is an extremely common phenomenon and that it helps to enhance scattered objects longevity; (2) In the same region, the so-called extended scattered TNOs are able to form via very long resonance trapping under certain conditions. Namely, if the body spends more than about 80% of its dynamical lifetime trapped in mean motion resonance(s) and there is the action of a $k + 1$ or $(k + 2)/2$ mean motion resonance (e.g., external mean

motion resonances with Neptune described as $(j+k)/j$ with $j=1$ and $j=2$ respectively). According to this hypothetical mechanism, 5–15% of current scattered TNOs would possess $q > 40$ AU thus probably constituting a significant part of the extended scattered disk; (3) Moreover, considering hot orbital initial conditions, it is likely that the transneptunian belt (or Edgeworth-Kuiper belt) has been providing members to the scattered disk, so that scattered TNOs observed today would consist of primordial scattered bodies mixed with TNOs that came from unstable regions of the transneptunian belt in the past. Considering the three points together, our results demonstrated that the scattered disk has been evolving continuously since early times until present.

Published in: Planetary and Space Science, 54, 87–100
For preprints, contact patryk@kobe-u.ac.jp
or on the web at http://harbor.scitec.kobe-u.ac.jp/~patryk/index-uk.html

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The Capture of Centaurs as Trojans

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Large scale simulations of Centaurs have yielded vast amounts of data, the analysis of which allows interesting but uncommon scenarios to be studied. One such rare phenomenon is the temporary capture of Centaurs as Trojans of the giant planets. Such captures are generally short (10 kyr to 100 kyr), but occur with sufficient frequency (~ 40 objects larger than 1 km in diameter every Myr) that they may well contribute to the present-day populations. Uranus and Neptune seem to have great difficulty capturing Centaurs into the 1:1 resonance, while Jupiter captures some, and Saturn the most ($\sim 80\%$). We conjecture that such temporary capture from the Centaur population may be the dominant delivery route into the Saturnian Trojans. Photometric studies of the Jovian Trojans may reveal outliers with Centaur-like as opposed to asteroidal characteristics, and these would be prime candidates for captured Centaurs.

To appear in: Monthly Notices of the Royal Astronomical Society
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or on the web at http://www.phim.unibe.ch/~horner/

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Search for Surface Variations on TNO 47171 and Centaur 32532

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We present photometric and spectroscopic observations of one Trans-Neptunian Object (TNO 47171 1999 TC_{36}) and one Centaur (Thereus also named 32532 2001 PT_{13}). Near-infrared data were acquired with the ISAAC instrument at one of the 8 m telecopes of the Very Large Telescope (VLT, ESO-Cerro Paranal, Chile), while visible data were obtained with the EFOSC2 instrument on the 3.6 m telescope of La Silla (ESO, Chile). These observations were performed to search for rotational variations for both targets. Water ice has been confirmed on both objects. The surface composition models of the targets are presented and discussed, and are also compared to previous observations available in the literature.

Published in: Astronomy & Astrophysics, 444, 977-982 (2005 December)

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Exploring the Surface Properties of Transneptunian Objects and Centaurs with Polarimetric FORS1/VLT Observations

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Polarization is a powerful remote-sensing method to investigate solar system bodies. It is an especially sensitive diagnostic tool to reveal physical properties of the bodies whose observational characteristics are governed by small scatterers (dust, regolith surfaces). For these objects, at small phase angles, a negative polarization is observed, i.e., the electric vector $\vec{E}$ oscillates predominantly in the scattering plane, contrary to what is typical for rather smooth homogeneous surfaces. The behavior of negative polarization with phase angle depends on the size, composition and packing of the scatterers. These characteristics can be unveiled by modelling the light scattering by the dust or regolith in terms of the coherent backscattering mechanism.

We investigate the surface properties of TNOs and Centaurs by means of polarimetric observations with FORS1 of the ESO VLT. We have obtained new broadband polarimetric measurements over a range of phase angles for a TNO, 50000 Quaoar (in the R Bessel filter), and a Centaur, 2060 Chiron (in the BVR Bessel filters). Simultaneously to the polarimetry, we have obtained R broadband photometry for both objects. We have modelled these new observations of Quaoar and Chiron, and revised the modelling of previous observations of the TNO 28978 Ixion using an improved value of its geometric albedo.

TNOs Ixion and Quaoar, and Centaur Chiron show a negative polarization surge. The Centaur Chiron has the deepest polarization minimum (-1.5 – 1.4 %). The two TNOs show differing polarization curves: for Ixion, the negative polarization increases rapidly with phase; for Quaoar, the polarization is relatively small ($\simeq -0.6$ %), and nearly constant at the observed phase angles. For all three objects, modelling results suggest that the surface contains an areal mixture of at least two components with different single-scatterer albedos and photon mean-free paths.

To appear in: Astronomy & Astrophysics

For preprints, contact `sbagnulo@eso.org`

or on the web at `http://arxiv.org/format/astro-ph/0601414`

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The Methane Ice Rich Surface of Large TNO 2005 FY_9: A Pluto-twin in the Trans-Neptunian Belt?

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The population of known large trans-neptunian objects (TNOs) is growing very fast and the knowledge of their physical properties is a key issue to understand the origin and evolution of the Solar System. In

this paper we studied the surface composition of the recently discovered TNO 2005 FY_9, one of the largest known TNOs (∼0.7 times the diameter of Pluto, i.e. 1600 km, if the albedo is similar, or 3100–1550 km in diameter assuming an albedo range $0.2 < p_V < 0.8$).

We report visible and near infrared spectra covering the 0.35-2.5 μm spectral range, obtained with the 4.2m William Herschel Telescope and the Italian 3.58m Telescopio Nazionale Galileo at "El Roque de los Muchachos" Observatory (La Palma, Spain). The spectrum of this large TNO is similar to that of Pluto, with an infrared region dominated by very prominent absorptions bands formed in solid CH_4. At wavelengths shorter than 0.6 μm, the spectrum is almost featureless and red. The red color most likely indicates the presence of complex organics, as has been hypothesized for Pluto and many other TNOs. The icy-CH_4 bands in this new giant TNO are significantly stronger than those of Pluto, implying that methane could be even more abundant on its surface. The existence of a volatile such as methane on the surface of 2005 FY_9, likely accompanied by N_2 and CO ices, coupled with its large size, make this Pluto-like TNO an excellent candidate to have an atmosphere comparable to Pluto's.

Published in: Astronomy & Astrophysics 445, 35L

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Analytic Gravitational-force Calculations for Models of the Kuiper Belt, with Application to the Pioneer Anomaly

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We use analytic techniques to study the gravitational force that would be produced by different Kuiper-Belt mass distributions. In particular, we study the 3-dimensional rings (and wedge) whose densities vary as the inverse of the distance, as a constant, as the inverse-squared of the distance, as well as that which varies according to the Boss-Peale model. These analytic calculations yield physical insight into the physics of the problem. They also verify that physically viable models of this type can produce neither the magnitude nor the constancy of the Pioneer anomaly.

Published in: Physical Review D, 72, 083004

PAPERS RECENTLY SUBMITTED TO JOURNALS

Orbits and Photometry of Pluto's Satellites: Charon, S/2005 P1, and S/2005 P2

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Submitted to: Astronomical Journal

For preprints on the web at `http://arxiv.org/abs/astro-ph/0512491`

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New Constraints on Additional Satellites of the Pluto System

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Submitted to: The Astronomical Journal

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The CFEPS Kuiper Belt Survey: Strategy and Pre-survey Results

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Discovery of a Low-eccentricity, High-inclination Kuiper Belt Object at 58 AU

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OTHER PAPERS OF INTEREST

The Solar System Beyond The Planets

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The Kuiper belt contains a vast number of objects in a flattened, ring-like volume beyond the orbit of Neptune. These objects are collisionally processed relics from the accretion disk of the Sun and, as such, they can reveal much about early conditions in the Solar system. At the cryogenic temperatures prevailing beyond Neptune, volatile ices have been able to survive since the formation epoch 4.5 Gyr ago. The Kuiper belt is the source of the Centaurs and the Jupiter-family comets. It is also a local analogue of the dust disks present around some nearby main-sequence stars. While most Kuiper belt objects are small, roughly a dozen known examples have diameters of order 1000 km or more, including Pluto and the recently discovered (and possibly larger) giant Kuiper belt objects 2003 UB_{313}, 2003 EL_{61} (a binary and a triple system, resp.) and 2005 FY_9.

To appear in the book "Solar System Update", Springer-Praxis Ed., Horwood, Blondel and Mason, 2006.

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Origin and Dynamical Evolution of Comets and their Reservoirs

Alessandro Morbidelli[1]

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This text was originally written to accompany a series of lectures that I gave at the '35th Saas-Fee advanced course' in Switzerland and at the Institute for Astronomy of the University of Hawaii. It reviews my current understanding of the dynamics of comets and of the origin and primordial sculpting of their reservoirs. It starts discussing the structure of the Kuiper belt and the current dynamics of Kuiper belt objects, including scattered disk objects. Then it discusses the dynamical evolution of Jupiter family comets from the trans-Neptunian region, and of long period comets from the Oort cloud. The formation of the Oort cloud is then reviewed, as well as the primordial sculpting of the Kuiper belt. Finally, these issues are revisited in the light of a new model of giant planets evolution that has been developed to explain the origin of the late heavy bombardment of the terrestrial planets.

35th Saas-Fee advanced course invited lecture
For preprints, contact `morby@obs-nice.fr`
or on the web at `http://au.arxiv.org/abs/astro-ph/0512256`

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Dust in Resonant Extrasolar Kuiper Belts – Grain Size and Wavelength Dependence of Disk Structure

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This paper considers the distribution of dust which originates in the break-up of planetesimals that are trapped in resonance with a planet. There are three grain populations with different spatial distributions: (I) large grains have the clumpy resonant distribution of the planetesimals; (II) moderate sized grains are no longer in resonance and have an axisymmetric distribution; (III) small grains are blown out of the system by radiation pressure and have a distribution which falls off $\propto 1/r$, however these grains can be further divided into subclasses: (IIIa) grains produced from pop I that exhibit trailing spiral structure emanating from the clumps; and (IIIb) grains produced from pop II that have an axisymmetric distribution. Since observations in different wavebands are sensitive to different sized dust grains, multi-wavelength imaging can be used to test models for the origin of debris disk structure. For example, a disk with no blow-out grains would appear clumpy in the sub-mm, but smooth at mid- to far-IR wavelengths. The wavelength of the transition is indicative of the mass of the perturbing planet. The size distribution of Vega's disk is modeled in the light of the recent Spitzer observations. The origin of the large quantities of pop III grains seen by Spitzer must be in the destruction of the grains seen in the sub-mm, and so at high resolution and sensitivity the mid- to far-IR structure of Vega's disk is predicted to include spiral structure emanating from the sub-mm clumps.

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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.

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