International Workshop
Trans Neptunian Objects
Dynamical and Physical Properties

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Abstract title: Provocative introduction

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No Abstract:
Otherwise where is the “provocation”? 
SESSION: DYNAMICS
Abstract: It is difficult to believe that it has been almost 15 years since our perception of the Solar System was changed drastically by the discovery of the first recognized Kuiper belt object. As the number of known objects increased (it is now well over 1000) it has become clear that the dynamical structure of this region of the Solar System is incredibly rich and complex. This has been a boon for those of us interested in the formation of the giant planets because this elaborate formation contains vital clues concerning how the orbits of the giant planets changed and evolved. One of the most puzzling questions about the Kuiper belt has to do with the amount of material that is currently present. Models of accretion argue that the region between ~30 and ~50 AU must have contained tens of Earth masses of material in order for the objects we see to grow. And yet, observations show that the region contains less than 0.1 Earth-mass. In this talk I will discuss the current theories about the mass depletion of the Kuiper belt and the origin of its complex dynamical structure.
Abstract: In this paper we study the role of dynamical friction on the evolution of a population of large objects \((m > 10^{22} \text{ g})\) at heliocentric distances \(> 70\) AU in the Kuiper Belt. We show that the already flat distribution of these objects must flatten further due to non-spherically symmetric distribution of matter in the Kuiper Belt. Moreover the dynamical drag, produced by dynamical friction, causes objects of masses \(\geq 10^{24} \text{ g}\) to lose angular momentum and to fall through more central regions in a timescale \(~10^9\) yr. This mechanism is able to transport inwards objects of the size of Pluto, supposing it was created beyond \(~50\) AU, according to a Stern & Colwell's (1997b) suggestion.
Abstract title: The Resonant Captures of TNOs
Authors: Ing-Guey Jiang, Li-Chin Yeh
Institute/s: Department of Applied Mathematics, National Hsinchu University of Education, Taiwan

Abstract: It has been well known that both the Solar System and the extra-solar planetary systems show the celestial bodies are engaged into mean motion resonances. In particular, a great fraction of TNOs are captured into 3:2 resonance but much less into other resonances. We investigate this strong contrast by considering both possible inward and outward migration that could have had happened in the early outer Solar System.
Abstract: At the orbital distances of Uranus and Neptune, the timescale for collisional accretion of a rocky core in the minimum mass solar nebula is problematically longer than the timescale for the dissipation of the gaseous nebula. Various formation scenarios have been proposed to reconcile the timescale problem, including formation of Uranus and Neptune at small orbital distances (e.g., Thommes et al. 2002) and a protoplanetary disk for which the bulk of the mass is concentrated in small sub-km sized debris (Goldreich et al. 2004). The latter model features the formation of several Neptune-mass planets which may have stirred the Kuiper belt (Chiang et al. 2006). Here we investigate this possibility by performing long-term n-body integrations of possible early outer solar systems, including Jupiter, Saturn, multiple Neptune-mass planets, hundreds of TNOs (treated as test particles), and a large population of small bodies (that damp the random velocities of planets via dynamical friction). We compare the outcomes of our simulations to the current orbital properties of the outer planets and TNOs in our solar system. Our simulations show that dynamical friction can be surprisingly effective at stabilizing the planetary systems and constrains this formation scenario.
Abstract: A myriad of bodies orbit beyond Neptune representing the remnants left after planetary formation. These transneptunian objects (TNOs) offer important clues on the origin and evolution of the solar system. We probe the transneptunian region by comparing up-to-date observations with our theoretical results, which consist of computer simulations (4-5Gyr) using tens of thousands of particles and also statistical analysis of physical properties (absolute magnitudes, albedos and sizes). Our main results are:

The classical region (40-47.5AU) is structured in inner (a<45AU) and outer (a>45AU) portions with inclination dependence. For the former, bodies suffer severe dynamical sculpting, especially those with low inclinations and/or associated with the 5:3, 7:4 and 9:5 resonances. In the outer portion, except near the 2:1 resonance, stable regions are abundant. Other dynamical and physical peculiarities are also discussed;

The evolution of members of the scattered disk (mostly a>48.5AU) is determined by multiple temporary resonance trapping (resonance sticking). Long term trapping (>3Gyr) or Kozai resonance associated in p:1 or p:2 resonances can lead to substantial increase of perihelion (40AU<q<70AU), thus contributing to the population of detached bodies beyond the Kuiper belt. Besides, we identified resonant scattered TNOs in the 9:4, 16:7, 7:3, 12:5, 5:2, 8:3 and 3:1 resonances. Important implications are also debated;

An accurate classification scheme is presented for the entire transneptunian region based on the dynamical behavior of TNOs and simulated particles. All resonant TNOs are identified and its properties characterized as well;

Large TNOs have albedos greater than the long assumed p=0.04 and increasing with size. Since all big bodies (>800km) would be able to sustain icy frosts or thin atmospheres composed of CH₄, CO or N₂, surface rejuvenation could explain the observed higher albedos;

Finally, we combine our results into a new self-consistent model that is able to explain most of the characteristics of the transneptunian region: the edge and excitation of the Kuiper belt, scattered disk orbital structure (including those with q>40AU), resonant populations in general, cold and hot classical TNOs, etc.
Abstract: The trans-Neptunian population appears as a much more complex dynamical structure than once thought. The Scattered Disk (SD) is one of the dynamical groups within such a population, consisting of objects with perihelion distances greater than 30 AU and semimajor axes greater than 50 AU. We also distinguish the Extended (or High-Perihelion) Scattered Disk (HPSD) whose perihelion distances are greater than 40 AU. A mean-motion resonance coupled with the Kozai mechanism is found to be the main responsible for raising the perihelia of scattered disk objects (SDOs) above 40 AU (Gomes et al. 2005. Cel. Mech. Dyn. Astron. 91, 109). The highest perihelion distance found was about 70 AU, which may explain the existence of some HPSDOs like 2000 CR_{105} (q≈44 AU), but not of Sedna (q≈76 AU) which might belong to the inner core of the Oort cloud, namely its current orbital configuration might have been influenced by external perturbers (e.g. passing stars) that were able to raise the comet's perihelion. Therefore, dynamical effects can explain the transit from SDOs to HPSDOs. An alternative hypothesis is that SDOs and HPSDOs formed closer to the Sun and then were driven outwards by resonant coupling with the accreting Neptune (Gomes 2003. Earth, Moon, Planets  92, 29).

Nearly 50% of the SDOs are found to be transferred to the Oort cloud (Fernandez et al. 2004), from which about 60% reach the Oort cloud with perihelia beyond Neptune's orbit (31<q<36 AU). This suggests that Neptune acts as a dynamical barrier, scattering most of the bodies to near-parabolic orbits before they can approach or cross Neptune's orbit in non-resonant orbits, thus favoring insertion in the Oort cloud. The different dynamical routes from the SD, to the HPSD and the Oort cloud, as well as the place where SDOs originally formed, and whether some objects may belong to the inner core of the Oort cloud will be discussed in this presentation.
Abstract title: The invisible hand of chaos in the formation and destabilization of Kuiper-belt binaries
Authors: Sergey A. Astakhov, Ernestine A. Lee and David Farrelly
Institute/s: Utah State University

The discovery that many trans-Neptunian objects exist as binaries is invaluable for shedding light on the formation, evolution and structure of the outer Solar system, e.g., the nature of the dynamics in debris disks. So far a total of 21 Kuiper-belt binaries (KBBs) are known plus the Pluto-Charon-P1-P2 quartet. Most KBBs contain partners having similar masses which follow large and eccentric mutual orbits. In this talk we briefly review current KBB formation models, all of which point to a primordial origin. We further propose a common dynamical explanation for the unusual compositional and orbital properties of KBBs based on four-body simulations in the Hill approximation.

Our calculations suggest that binaries are produced through the following chain of events. Initially, long-lived quasi-bound binaries form by two bodies getting entangled in thin layers of dynamical chaos produced by solar tides within the Hill sphere (i.e., chaos-assisted capture). Next, energy transfer through gravitational scattering with a low-mass intruder moves the binary into a nearby non-chaotic (stable) zone of phase space. Finally, the binary hardens (loses energy) through a series of relatively gentle gravitational scattering encounters with further, low-mass, intruders. This produces binary orbits that are well fitted by Kepler ellipses. Dynamically, the overall process is strongly favoured if the original quasi-bound binary contains comparable masses. Unexpectedly, chaos plays a twin role in the stabilization and destabilization of nascent binaries; it provides a mechanism for the formation of transient binaries but selectively destabilizes binaries containing partners having very unequal masses. This suggests that the observed preponderance of roughly equal-mass ratio binaries is a real effect and not simply an artefact of an observational bias for widely separated, comparably bright objects. Nevertheless, we predict that a sizeable population of very unequal-mass Kuiper-belt binaries is probably awaiting discovery.
Abstract title: Capture of Irregular Moons by 3-Body Reactions
Authors: Nesvorny D. et al.

Abstract: The irregular moons of the jovian planets are an enigmatic part of the Solar System inventory. Unlike regular satellites, the irregular moons revolve around planets at large distances in inclined and eccentric orbits. Their origin, which is intimately linked with the origin of planets themselves, has yet to be adequately explained. We discuss the possibility that the irregular moons were captured from the circumsolar planetesimal disk by 3-body gravitational reactions. These reactions may have been a frequent occurrence during the time when the outer planets migrated in the planetesimal disk.
Abstract: We will review the orbit computation problem for the transneptunian population. For these distant objects, the problem is characterized by their short observed orbital arcs, which are known to be coupled with large uncertainties in orbital elements (e.g. Virtanen et al. 2001). Currently, the observations of even the best observed objects, such as the first-ever TNO, Pluto, cover only a small fraction of their revolution.

Furthermore, of the ~1000 objects discovered since 1992, roughly half have observations from only one opposition. To ensure realistic analyses of the population, e.g., in the derivation of unbiased orbital distributions or correlations between orbital and physical properties, realistic estimation of orbital uncertainties is important.

We describe the inverse problem of short-arc orbit computation and its statistical treatment. The complete solution to the problem can be given in terms of the orbital-element probability density function (p.d.f.), which then serves as a starting point for any further analysis, where knowledge of orbital uncertainties is required.

We give an overview of the variety of computational techniques developed for TNO orbital uncertainty estimation in the recent years. After presenting the current orbital distribution, we demonstrate their application to several prediction problems, such as classification, ephemeris prediction and dynamical analysis of unusual objects. We conclude with some future prospects for TNO orbit computation concerning the forthcoming next-generation surveys, including the anticipated evolution of TNO orbital uncertainties over the coming decades.
Abstract: Using visual observations that were reported 140 years ago in the Comptes Rendus de l’Academie des Sciences de Paris, we have determined the atmospheric trajectory and the orbit of The Orgueil meteorite, which fell May 14, 1864, near Montauban, France. Despite the intrinsic uncertainty of visual observations, we were able to calculate a reasonably precise atmospheric trajectory and a moderately precise orbit for the Orgueil meteoroid. The atmosphere entry point was ~70 km high and the meteoroid terminal point was ~20 km high. The calculated luminous path was ~150 km with an entry angle of 20°. These characteristics are broadly similar to that of other meteorites for which the trajectory is known. Five out of six orbital parameters for the Orgueil orbit are well constrained. In particular, the perihelion lies inside the Earth’s orbit (q~0.87 AU), as is expected for an Earth-crossing meteorite, and the orbital plane is close to the ecliptic (i~0°). The aphelion distance (Q) depends critically on the pre-atmospheric velocity. From the calculated atmospheric path and the fireball duration, which was reported by seven witnesses, we have estimated the pre-atmospheric velocity to be larger than 17.8 km/sec, which corresponds to an aphelion distance Q larger than 5.2 AU, the semi-major axis of Jupiter orbit. These results suggest that Orgueil has an orbit similar to that of Jupiter-family comets (JFCs), although an Halley-type comet cannot be excluded. This is at odds with other meteorites that have an asteroidal origin, but it is compatible with 140 years of data-gathering that has established the very special nature of Orgueil compared to other meteorites. A cometary origin of the Orgueil meteorite does not contradict cosmochemistry data on CI1 chondrites. If CI1 chondrites originate from comets, it implies that comets are much more processed than previously thought and should contain secondary minerals. The analysis of cometary samples by the Stardust mission will provide a unique opportunity to corroborate (or contradict) our hypothesis.

More largely, we will discuss the possibility of meteorites being delivered by the KBO bodies.
Abstract title: Dynamics of Centaurs
Authors: Dones L.(1), Levison H.F.(1), Duncan M.J.(2), Brasser R.(2), Weissman P.(3)
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Abstract: We will review the orbital and absolute magnitude (size) distributions of Centaurs; the long-term orbital evolution of the Centaur population; the source regions of Centaurs, such as the scattered disk/Kuiper belt; and the relationship of Centaurs to other small-body populations, such as Jupiter-family comets, Trojans, and irregular satellites. We will also discuss the stability of Centaur binaries, which is of interest due to the recent discovery of the binarity of (42355) 2002 CR46 (Noll et al., IAU Circular 8689).
Abstract: Binary systems among trans-Neptunian objects (TNOs) are relatively common when compared to the population of main-belt asteroids. The knowledge of the orbital parameters of these systems (mainly the eccentricity but also the inclination) is of high importance to shed light on their formation scenario (e.g. Astakhov et al. [1]). Moreover the measures of the semi-major axis and orbital period enables one but to accurately derive their mass and subsequently an estimation of their bulk-density and/or albedo.

We have developed a method for the computation of the orbits of (resolved) visual binaries in a way similar to the statistical ranging' technique of Virtanen et al. [2]. The method is particularly well adapted to the determination of the bundle of possible orbits in the case of few observations or low redundancy (which is often the case for these faint objects when observed for instance with the HST), providing both the nominal solutions with their associated confidence region. Combining the Thiele-Innes method to the Monte-Carlo technique, the phase-space to explore is reduced to a single dimension (the orbital period) which makes the computation practically fast.

The method is presented with an application to the data of known systems 2001 QT297 observed with Gemini [3], and the system 1999 RZ253 observed with HST/ACS [4]. We last show how the observing strategy can be optimized in order to uniquely derive the orbital inclination for these distant (small parallax) objects. Additionally it is shown how the present methodology can be extended to the case of (unresolved) astrometric binaries.

SESSION: DISCOVERIES
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Abstract title: The big objects population

Abstract: not available
Abstract: Scientific progress in the field of Kuiper Belt studies now requires the acquisition of a large and well-characterized TNO data set which is free of orbital bias and which furnishes enough 'interesting' objects (rare on the sky) to improve our understanding of portions of the Kuiper Belt. Insight into the current structure and formation process of the Kuiper Belt is limited by the lack of completely-documented and uniform surveys which locate and track objects so that relative belt populations can be reliably determined. Correctly determining the orbital structure of the outer Solar System is a critical step for theoretical modelling of the Kuiper belt; similar modelling for the asteroid belt over the last decade, using a few well-characterized surveys, has produced excellent advances in understanding the structure of the inner solar system, the distribution of the near-Earth objects, and the impact rates on the terrestrial planets.

The Canada-France-Hawaii Telescope's Legacy Survey includes an ecliptic survey component intending to provide an analogous advance in our understanding of the outer Solar System. While large numbers of new objects are needed in order to obtain a good statistical understanding of the belt, the compilation of this orbital information occurs over a 3-5 year time scale. The design of the survey is to detect one object per Megacam field when near the ecliptic. The density of Kuiper Belt objects is a strong function of ecliptic latitude. Even a few degrees North and South of the orbital plane, the density of objects begins to drop. The survey observations are made on or near (+/-2 deg.) the ecliptic plane to produce the maximal discovery rate. The short exposure times ensure that detected objects are bright enough to track easily and short exposures are of course necessary to permit wide sky coverage.

A major goal of the survey is to discover the spatially rare objects as these are most likely to lead to major advances in this field. Given that the discovered objects are imaged many times at other facilities, photometric precision and image quality are not driving factors in these observations. Rather, correct time spacing of observations and coverage of the ecliptic are the major concerns.

The two most important products from the CFHTLS-VW for Kuiper Belt science are a "unbiased" database of orbital elements of TNOs, and the characterisation of the survey that discovered them. To provide those products to the community, we have developed a Web interface to the database of TNOs discovered in CFHTLS-VW, and a Web-accessible survey simulator. Objects discovered during the first year of CFHTLS have all come to their third opposition, and a large fraction of them have been observed with an arc of 2 years. We will present this first batch of objects and show first constraints on Kuiper Belt models that can be derived from comparison between model objects "detected" through the survey simulator and actual detections.
Abstract: The number of binary and multiple systems known in the Kuiper Belt is continuing to grow rapidly both in number and diversity. The number of known binary transneptunian objects is approaching 30. In the last year the first multiple systems have been discovered, the first binary Centaur has been found, and a number of very asymmetric systems are now known. The frequency of binaries in the cold classical disk appears to be significantly greater than in other, dynamically hotter families suggesting the cold classical population formed more binaries to begin with and/or binaries that did form had a better chance of survival. Statistics for the hot populations are insufficient to reach similar conclusions, although counts are suggestive of further differences between dynamical families.

Binaries are extremely useful as tools for measuring physical properties of transneptunian objects, starting with mass. Orbits have been determined for a subset of the known binaries and masses have been determined for eight systems. System masses can be used in conjunction with observed absolute magnitudes to constrain albedo and density. From these data and others it has become apparent that the average albedo of transneptunian objects is near 0.1 with a wide dispersion. There are no clear trends of albedo with size, dynamical class, or color. The density of one binary system has been determined by combining the binary system mass with Spitzer-derived diameter and is surprisingly low.

The current number of known transneptunian objects is over 1000. Based on the sample we have so far, we estimate that there are 100-300 detectable binaries in this group, an order of magnitude more than are currently known. Discovery and study of binaries will continue to be an important component of Kuiper Belt research for the foreseeable future.
Abstract: For the last five years we have been carrying out recovery observations of newly discovered KBOs with the Magellan Telescopes at Las Campanas Observatory. We target objects recently discovered by the Deep Ecliptic Survey (DES; Millis et al. 2002, AJ 123, 2083; Elliot et al. 2005, AJ 129, 1117], or those that have not been dynamically classified, with the goal of improving the quality of the orbit and thereby increasing the number of objects able to be used in dynamical and correlated physical studies of the belt as a whole. Using MagIC, a high resolution imager, we have discovered 3 binary KBOs - 88611 (2001QT297), 2003QY90, and 2005EO304 - in addition to a binary in the original DES discovery images, 2003UN284. We are in the process of characterizing the orbits and resolved rotational light curves of these objects. We fit the light curve of the secondary component of 88611 with a single-peaked period of 5.50 ± 0.02 hours, while the primary component appears to be non-variable above the measurement errors (0.05 magnitudes). Neither component appears to be color variable. The components of 2003QY90 are both highly variable yielding single-peaked rotation periods of 3.4 ± 1.1 and 7.1 ± 2.9 hours with amplitudes of 0.34 ± 0.12 and 0.90 ± 0.36 magnitudes, respectively (Kern & Elliot 2006, Icarus, in press). The rotation periods are comparable to those of other non-binary KBOs although distinct from that of an identified contact binary (Sheppard & Jewitt 2004, AJ 127, 3023). We estimate the frequency of widely spaced (separations > 0.5 arcseconds) binary KBOs from our survey and recovery observations and find the frequency of binary KBOs versus discovery separation to be related by an inverse power law. Comparison of our results with the binary frequency predicted by the Goldreich et al. 2003 (Nature 420, 643) model will be discussed. Our work is supported, in part, by the NSF grant AST-0406493 and the NASA grant NNG04GF25G.
Abstract title: Modelling the populations of Trans-neptunian objects
Authors: Campo Bagatin, A.; Benavidez, P.G., Bernabeu, G.
Institutes: Universidad de Alicante

Abstract: The Trans-Neptunian region is yet another example of a collisional system of small bodies in the Solar System. In the last decade the number of TNOs with reliable orbital elements is steadily increasing and we can begin to try and compare collisional evolution models to observed populations.
With this aim we are developing a model that takes into account the known physics of the fragmentation of icy/rocky bodies, including recently published experimental results, and that considers the different orbital characteristics of the Trans-Neptunian regions (plutinos, classical belt and scattered disk) and their mutual interactions. What was the primordial distribution in this region? Is the Trans-Neptunian belt collisionally relaxed? What fraction of the TNO population is likely constituted by gravitational aggregates? How did Neptune's migration affect the distribution of TNOs? First results are presented.
Abstract: The Taiwanese-American Occultation Survey (TAOS) is a survey for occultation of bright stars by small Kuiper Belt objects. TAOS has now entered the data collection phase and is acquiring large amount of data in fast photometry wide field observations of selected 3 square degree fields. Predicted occultations by asteroids have been successfully detected demonstrating the capability of the system. In this talk the current status of the TAOS system will be summarized. The plan for the data analysis and efficiency determination will be presented, and focusing on two simple Kuiper Belt models, the expected TAOS event rate will be discussed.
Abstract: Whipple is a proposed Discovery mission to perform a space-based wide-field occultation survey for small objects in the outer Solar System, from the Kuiper Belt all the way to the Outer Oort Cloud. The telescope will be sensitive to KBOs as small as 300 meters, and have the capability to discover hundreds of new, previously undetectable objects over the course of the mission lifetime. In this talk, the Whipple mission will be described, the expected results of the survey will be presented and the scientific impact of the mission will be summarized.
Abstract: We present here the preliminary results for the first attempt to survey the sub-kilometre radius KBO population by stellar occultation. Using the unique capabilities of the 1.2m UK Schmidt Telescope (Anglo Australian Observatory, Siding Spring, Australia), in conjunction with the 6df Spectrograph (set up in straight-through mode), and by simultaneously monitoring ~100 suitably selected stars at a time, we were able to embark upon an occultation observation program which yielded ~7,000 hours of stellar light curves, with ~10 millisecond resolution.

The observation program was conducted over 16 nights during bright of moon periods in mid 2005. The initial data reduction indicates that we have captured many events which resemble occultation events, in so far as the light curves of recorded events typically match that which may be expected when a small KBO occults a distant star.

Most logged events are spread over many pixels, with 10 pixels (corresponding to 100 milliseconds) being the typical event duration. By simultaneously monitoring many stars in the same field, occultations caused by close-in earth bound objects are readily eliminated.

Of the 16 nights observing, 15 nights were spent monitoring blue stars located at ~2kpcs. As a sanity check, one night's observing run was dedicated to monitoring ~100 stars of mainly close F and G class stars in the same field.

The event statistics for the distant and the close star cases are consistent with occultations caused by KBO's. In particular, for the close large disk stars, there are very many more shallow events, and no deep occultation events.

It is estimated that many of the events logged correspond to occultations which would be caused by objects down to sub-kilometre radius, perhaps even down to 500m radius.

As the next step, it is hoped to construct a purpose-built ~2,000 fibre instrument and to conduct a complete survey of the Kuiper Belt.
Abstract title: The invisible Kuiper Belt Explored by Stellar Occultations
Authors: F. Roques(1), C. Alcock (2), A Doressoundiram (1), G. Georgevits (3)
Institute/s: (1)Paris Observatory, (2) Pennsylvania University, (3) UNSW

Abstract: Stellar occultation is a powerful tool for exploring the small end of the Kuiper Belt size distribution and the outer region of the solar system. It is a complementary approach for the exploration of the Trans Neptunian population. Stellar occultations by objects of the solar system is a fruitful method for studying planet atmospheres, ring systems and small bodies such as satellites and asteroids. The principle of stellar occultation is to record the stellar flux during the transit of the occulting object. This method allows detection of objects which are too faint to be observed directly. Occultation by a KBO is a very brief phenomenon involving Fresnel diffraction. The key parameters of this technique will be reviewed: - the choice of the target stars - the direction of observation -the instrumentation characteristics - the possible observational artefacts - the influence of observing conditions. Two approaches are possible: Automatic observation of fields of stars with small telescopes organized to scan the kilometer-sized objects population. Observation of well chosen stars with large telescopes permits one to record the diffracting shadow of hundred-metre size objects. Stellar occultations by known objects are difficult to predict because of the small angular diameter of the objects but they allow us to measure the object size and they can provide information on the atmosphere, as has already been done for Pluto and Charon.
SESSION: EVOLUTION
Abstract: Collisions have played an important role in creating and sculpting the population of trans-Neptunian objects (TNOs). In the earliest stages, low-velocity collisions led to the accretion of large TNOs from a population of small planetesimals. Work on this subject [eg. 1-4] suggests that the primordial TNO population must have been substantially more massive than it currently is in order for large bodies like Pluto to accrete within the age of the Solar System. Following the accretion and dynamical excitation of TNOs, more energetic collisions could have played a role in reducing the mass of the TNO population to its current level, and that collisional activity could be responsible for shaping the current size distribution of TNOs [eg. 1,5-10]. In addition, it has been suggested that collisional effects may be responsible, at least in part, for the differences between the colors of low- and high-inclination Kuiper belt objects [eg. 11-14]. Most work on these subjects assumes that the TNO population formed in its current location. Recent dynamical models [eg. 15] suggests that those bodies instead formed closer to the Sun and were pushed-out to their present locations during the migration of the outer planets. In such a scenario, dynamical depletion dominates over collisional grinding as a mass-loss mechanism, although collisional evolution could still play an important role in the sculpting of the TNO size and color distributions. A full understanding of the collisional evolution of the trans-Neptunian population thus requires consideration of its dynamical evolution as well.

This review talk will summarize the work to date on the collisional evolution of the TNO population and highlight the outstanding questions and uncertainties that remain, with a specific focus on the implications of different dynamical models [eg. 15,16] for the collisional history of the TNO population. In addition, I will discuss the observational constraints that can be placed on the collisional history of TNOs, namely observational surveys that can constrain its current size and color distributions [eg. 17,18,11], and experimental constraints on the impact strength of TNOs [eg. 19-22], which is a necessary input parameter for any collisional modeling.

References:

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Abstract title: Thermal evolution

Abstract: not available
Abstract: The irregular moons of the giant planets are intriguing minor bodies of the outer Solar System. Their orbits around the planets are characterized by semimajor axis an order of magnitude greater than those of the regular satellites and show high values of eccentricity and inclination. Such dynamical characteristics argue against an in-situ formation and suggest they are captured bodies, but to now there is no clear consensus on their region of formation or on the physical processes responsible for their capture. We concentrated our attention on Saturn since the number of its known irregular satellites almost doubled during this last year and since a significant amount of data have been recently taken by Cassini-Huygens instruments on Phoebe, which is now the better characterized minor body of the outer Solar System. Our investigation of the present day structure of the irregular satellites of Saturn aims to understand which ones of the dynamical characteristics we observe today are primordial and bring informations on the original captured bodies and which ones are a product of the secular evolution of their orbit under the perturbative influence of the Sun and the other giant planets. Our work has been divided into three main tasks: 1) computation of the mean orbital elements of these satellites 2) search for collisional families or families remnants 3) investigation of the potential regions of formation of the parent bodies and of the physical constrains on their collisional capture. Our results suggests that Saturn's irregular satellite system is subjected to a strong sculpting by the tidal effects of the Sun and Jupiter, thus indicating that the system is highly dynamically evolved. Nevertheless, we found indications of possible collisional families. Finally, we found that the actual orbital behaviour of the irregular satellites can bear indications on the dynamical nature of the parent bodies only if capture processes took places inside a narrow range of physical conditions.
Abstract: The Centaurs are a dynamical class of minor bodies in the Solar System, moving on highly chaotic orbits with perihelion lying between Jupiter’s orbit and Neptune’s orbit, with calculated orbital lifetimes less than 107 years. They reside in a region of the Solar System where many volatile species begin to have significant sublimation rates, and several examples of cometary activity have been observed among the group. Sudden changes in their activity level can be observed. As a recent example, the Centaur 174P/2000 EC98 (60558) was inactive at least up to April 2003, when photometry was not contaminated by any cometary activity down to magnitude R = 27/arcsec2, but a substantial coma was detected around this Centaur on December 2005. The question of activity among Centaurs is part of a wider debate on the activity of minor bodies at great distance from the Sun. Several short period comets have been observed with a coma and even a well developed dust tail at distances larger than 3.5 AU (the canonical distance of H2O sublimation). This long distance activity has been observed also in long period and new comets, and most remarkable is the case of the comet C/1995 O1 (Hale-Bopp) with its activity at 13.1 AU from the Sun and at 18-20 AU. Even in the Kuiper Belt, probable cases of cometary activity have been reported for the TNOs 1996 TO66 and for 1999 TD10.

The source of activity is not known for most of the active Centaurs. The activity at distances from the Sun greater than 3-4 AU cannot be explained with water sublimation, but could be better explained with the sublimation or the release of very volatile gases, in particular CO. The source of a CO-driven activity should be found under the surface, where the internal temperatures could drop quickly to very low values, and so it is expected this loss rate can change very slowly in time after its onset of activity. Moreover, the CO-driven gas and dust flow is supposed to leave the body along most of its orbit and from everywhere on the surface, due to the low sublimation temperature and the depth of sublimation and transition fronts. The dust release from the nucleus surface due to CO drag is then expected to be different from that due to water.

Here we present the analysis of the dust environment of the active Centaur P/2004 A1 (LONEOS), which is characterised by a very interesting dynamical history. It experienced a very recent close encounter with Saturn, which changed its orbital parameter and determined a sudden drop in its perihelion distance. Observations here presented refer therefore to the first passage of this object at its reduced perihelion distance. The Centaur showed an asymmetric coma and a Neck-Line extending at least up to 1.5 x 10^5 km in the solar direction, emitted half an orbit before the observation. The Afp value measured in a 5'' aperture is 334 ± 15 cm, indicating a significant dust production rate, comparable with that of several Short Period Comets at much lower heliocentric distances. The emitted grains are larger than 1 cm, and the application of an inverse numerical model gives as an output a dust production rate around 100 kg s^{-1} during the last ten years. For a Rn = 10 km and a maximum size of the uplifted grain > 3 cm, a CO molecular abundance Q > 10^{30} mol s^{-1} is required if it is uniform over all the surface, making P/2004 A1 (LONEOS) the Centaur with...
the highest CO loss rate ever observed among the class. The results will be discussed also in view of future investigations to be performed on this Centaur and on other members of the class.
Abstract: The discovery of large trans-Neptunian bodies such as (90377) Sedna and 2000 CR105 demonstrates that there are bodies that have had their pericentres decoupled from Neptune, possibly because of a relatively close stellar passage (Morbidelli & Levison 2004). It is likely that the Sun formed in an embedded star cluster of central densities ranging from 10^2 to 10^5 M_sun/pc^3 containing 100-1000 members (Lada & Lada, 2003). The extensive numerical simulations of Brasser, Duncan & Levison (2006) have demonstrated that an Inner Oort cloud with objects on orbits similar to those of (90377) Sedna and 2000 CR105 can be produced if the Sun was in an embedded star cluster and encountered stellar densities \( \sim 10^4 \) M_sun/pc^3 for at least \( \sim 1 \) Myr subsequent to the formation of Jupiter and Saturn.

Here we report on ongoing extensions of the simulations of Brasser, Duncan & Levison (2006) that include the effects on the planetesimals of aerodynamic drag due to the primordial Solar nebula. Since the deceleration by the drag is inversely proportional to an object’s radius, the orbits of typical comet-sized bodies may be strongly influenced while those of objects as large as Sedna are largely unaffected. The minimum-mass Hayashi model (Hayashi, 1981) is used as a reference density distribution, although variants with different densities, different density profiles and inner and/or outer disk truncations and gaps are also being studied. In most runs, only Jupiter and Saturn are present on their pre-LHB orbits (Jupiter at 5.45 and Saturn at 8.18 AU), although in some cases Uranus and Neptune are included (at 11.5 and 14.2 AU respectively). Preliminary results indicate that if the minimum-mass distribution persists for more than \( \sim 1 \) Myr subsequent to the formation of Jupiter and Saturn, very few km-sized comets end up in the (Inner) Oort cloud. Instead, all these comets either end up on near-circular orbits inside of Jupiter or outside of Saturn, the latter usually between 10 and 16 AU. When Uranus and Neptune are included, many of the comets end up on circular orbits outside of Neptune. For lower densities, this phenomenon is less pronounced and some material is able to reach the (Inner) Oort cloud, but preliminary results indicate that the efficiency is lower than that without any gas present. The effects of time-varying densities and inner and/or outer disk truncations will be explored and discussed.

On the other hand, the deposition of large amounts of material beyond the outermost large body (Saturn or Neptune) could have important consequences for accretion and/or subsequent planetary migration as well as planetesimal scattering and (Inner) Oort cloud formation. These aspects will be briefly discussed and are to be explored further in the near future.
Abstract: The Kuiper belt is often described as a primordial reservoir, although its largest members (e.g., Pluto) are arguably highly evolved. A complex thermal and internal evolution for large Kuiper Belt objects (KBOs) is not hard to understand [e.g., McKinnon et al. 1997, in Pluto and Charon, S.A. Stern and D.J. Tholen, eds., pp. 295-343; McKinnon 2002, ESA SP-500, 29-38]. New constraints on large KBO densities, however, suggest that there may be distinct bulk compositional classes as well, rather than simply spectral and surface compositional classes. Data from light curves, when interpreted in terms of hydrostatic triaxial shape [e.g., 20000 Varuna; Jewitt and Sheppard 2002, A.J. 123, 2110-2120; Sheppard and Jewitt 2002, A.J. 124, 1757-1775], or masses inferred from binaries, when coupled to vis-IR determined sizes [1999 TC36; Stansberry et al. 2006, Ap. J. 643, in press], point towards some rather low densities, some even possibly lower than 1 g/cc. While high porosities (>50%) are certainly permitted for small, “microgravity” bodies some km to tens of km in scale [e.g., Shoemaker-Levy 9; Asphaug and Benz 1996, Icarus 121, 225-248], the situation for the larger KBOs, hundreds to thousands of kilometers in scale, where internal pressures cannot be neglected, is quite different. Even without thermal-creep-driven densification, water ice rubble will “crush up” under moderate pressures: experiments on 77 K ice show strong loss of porosity over the 1-10 MPa pressure range, whereas ~10% residual porosity can retained at pressures in excess of 100 MPa [Durham et al. 2005, Geophys. Res. Lett. 32, L18202]. (Central pressures of 1, 10, and 100 MPa are obtained in bodies of 70-, 220-, and 700-km radius, respectively, for a uniform density of 1.2 g/cc.) Thus it does not seem possible to explain the putative very low density, large KBOs if their solid (or grain) densities are similar to that of Pluto or Triton (corresponding to an ~70/30 rock/ice mixture by mass). Either some large KBOs are icier than this, or the physical models used to infer the low densities are significantly incomplete. In contrast is the KBO 2003 EL61, where a hydrostatic triaxial figure implies a density significantly greater than that of Pluto [Rabinowitz et al. 2006, Ap. J 639, 1238-1251]; either some large KBOs are more rock-rich than Pluto or the Jacobi figure interpretation is not the whole story. The question is how to make ice-rich and/or rock-rich KBOs. If larger KBOs differentiate, are collisions during the dynamical excitation and clearing of the Kuiper belt sufficient to strip the ice mantles off some and create a new generation of ice-rich mid-size KBOs and comets? It is very hard to imagine this; in the present-day Kuiper belt the catastrophic disruption size is just 4 km or so [Durda and Stern 2000, Icarus 145, 220-229]. The compositional zonation of the asteroid belt in the inner Solar System is due to differential, temperature-controlled condensation, early heating of parent bodies (even small ones), and dynamical mixing. Is there a similar role for short-lived radiogenic heating in the Kuiper belt? As for long-term radiogenic heating (which is assured), it, when abetted by the low conductivities of porous regoliths, can mobilize low-melting-point icy lavas in larger KBOs [McKinnon 2002]. Even water-ice melting, which would lead to whole-scale differentiation and formation of rocky cores is possible if solid-state convection is suppressed [McKinnon et al. 1997]. Low gravity implies low buoyancy, and this and the strongly temperature-dependent viscosity of water ice work against convection in KBOs, but it is certainly possible at the Pluto scale. Melting and differentiation lead (though not inevitably) to internal aqueous layers...
(“oceans”), which depending on KBO scale and rock fraction, may persist throughout Solar System history. Perversely, water-ice convection above such an ocean at late times can become “too efficient” for the radiogenic heat supply; this can lead to convective shut-down, and an epoch of ocean thickening [McKinnon 2006, Icarus, in press]. In summary, there appear to be wide variations in bulk density among the larger KBOs, and if porosity is not the explanation at these scales, then we are left with variations in the ice/rock ratio. Possibilities for how this came about need to be explored. These should have important consequences for understanding the KBOs and the early history of the Kuiper belt.
Abstract title: Thermal model of the active Centaur P/2004 A1 (LONEOS)
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Abstract: Discovered in 2004, the active object P/2004 A1 (LONEOS) is classified as a Centaur due to its orbital parameters (semimajor axis 7.896 AU, perihelion distance 5.463 AU, eccentricity 0.308). When it was observed at TNG (La Palma, Canary Islands) and CAHA (Calar Alto, Spain) during the spring of 2005 (Epifani et al., 2006, submitted to A&A), showed a very high level of activity, with a well developed coma and tail. The heliocentric distance at the moment of observation was 5.5 AU: the driver of this activity should not have been water, but very probably gases such as CO. The dynamical history of this object is also peculiar. It had in 1992 a close encounter with Saturn that changed a previous stable orbit: the perihelion distance passed from 9.78 AU to 5.46 AU, the aphelion distance passed from 14.56 AU to 10.37 AU. We present here the results of the simulation of the thermal evolution of this body, followed before and after its jump. This thermal evolution and differentiation model, tested and applied many times on real comets and KBOs, is able to give, on the basis on an assumed initial nucleus composition, gas and dust fluxes. Our goal is to give a possible explanation for the activity of this body, quite unusual if not unheard of at this distance.
SESSION : LABORATORY EXPERIMENTS
Abstract: Many observational and experimental studies have shown that solar wind and cosmic ions affect the surface properties of airless bodies in the Solar System. Effects include chemical and structural modifications, as well as formation of new species. Since visible and near-infrared reflectance spectra of trans-Neptunian objects and Centaurs revealed a great variety of spectral colors (only partially explained by a different composition), it is widely believed that a competition between aging (e.g., cosmic ion irradiation) and rejuvenating (e.g., impacts with space debris, cryovolcanism, etc.) processes produces the observed color distribution.

We review recent experimental results obtained after ion irradiation of silicates, ices, and carbons, studied through Vis-NIR (0.25÷2.7 microns) diffuse reflectance spectroscopy. In particular, irradiated silicates show a strong spectral reddening and darkening, related to the energy lost by ions through elastic collisions (e.g., creation of displacements, vacancies) inside the target (Strazzulla et al., 2005; Brunetto & Strazzulla, 2005). In the case of natural complex hydrocarbons (asphaltite and kerite), that are very dark in the visible and have red-sloped spectra in the visible and near-infrared, irradiation-induced carbonization gradually neutralizes the spectral slopes of these red organic solids, and spectral color alteration increases with increasing contribution of elastic energy loss (Moroz et al., 2004).

Finally, irradiation of frozen (16÷80 K) methanol (CH3OH), methane (CH4), and benzene (C6H6), with 200 keV H+ and Ar+ ions, and 400 keV Ar++ ions, up to a dose released to target molecule of about 350 eV per 16 amu, evidences a strong reddening and darkening of the spectra, due to the formation of an organic (C-rich) refractory residue (Brunetto et al., 2005; Brunetto et al., 2006). These behaviors are compared with the spectra of some Centaurs and TNOs; we find that many icy objects in the outer Solar System may have grown an irradiation mantle, produced by cosmic ion irradiation of simple hydrocarbons and/or alcohols. For some of these objects we also perform a fit of the spectra using the Hapke model (following the approach of Roush, 1994, and Cruikshank et al., 1998).

Abstract: The population of known trans-neptunian objects (TNOs) is growing as new members are being detected and further characterized by both visible and near-IR observers. Good evidence exists that the spectra of TNOs are dominated by absorptions of either water or methane ice. The presence of N2, CO, and possibly NH3 ices is also likely. During their lifetimes, TNOs experience a weak, but constant energetic ion radiation environment that drives chemical reactions in their surface ices, ultimately producing a non-volatile residual material. To better understand the formation of more-complex and less-volatile molecules on TNO surfaces, we have performed radiation chemical experiments on icy materials at 10 - 100 K. Gas-phase molecules, or molecular mixtures, are frozen in a vacuum chamber and then exposed to a beam of MeV protons to mimic cosmic-ray bombardment. Changes in ice composition are followed in situ with IR spectroscopy after irradiations, and during warming. In this presentation we will focus on the identity of low temperature and thermally-stable radiation products in known outer solar system ices. Our results address likely radiation chemical mechanisms, the stability and evolution of species, the identification of molecules awaiting detection, and implications for astrobiology. This research is funded through NASA’s Planetary Atmospheres, Planetary Geology and Geophysics programs and the Goddard Center for Astrobiology.
Abstract title: Laboratory data on ices, silicates and organics for TNOs and Centaurs: what is missing?
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Abstract: A few species have been firmly identified in spectra of TNOs (including Pluto and Charon) and Centaurs. These are: ices of water, nitrogen, carbon monoxide, and methane. In addition, an absorption at 2.3 micron detected in spectra of two objects (Centaur Pholus and TNO 55638) has been attributed to methanol (or a photolytic product of methanol) ice, and an absorption at 2.2 micron seen in spectra of Charon (and maybe Quaoar) has been tentatively assigned to a mixture of ammonia and ammonia hydrate. Furthermore, a few silicates (anhydrous and hydrous) and a few organics have been considered in spectral models of some of these objects to account for broad unidentified signatures, to reproduce spectral slopes (shapes) or to explain the measured low albedos. We briefly review the laboratory data that have been used so far to interpret the spectra and we discuss what is missing.
Abstract: We will present the products of new laboratory measurements of ices relevant to Trans-Neptunian Objects. We have calculated the real and imaginary indices of refraction for amorphous and crystalline H2O-ice and also H2O-rich ices containing other molecular species. We create ice samples by condensing gases onto a cold substrate. We measure the thickness of the sample by reflecting a He-Ne laser off of the sample and counting interference fringes as it grows. We then collect transmission spectra of the samples in the wavelength range from 0.7-22 µm. Using the thickness and the transmission spectra of the ice we calculate the imaginary part of the index of refraction. We then use a Kramers-Kronig calculation to calculate the real part of the index of refraction (Berland et al. 1994; Hudgins et al. 1993). These optical constants can then be used to create model spectra for comparison to spectra from Solar System objects, including TNOs. We will summarize the difference between the amorphous and crystalline H2O-ice spectra. These changes include weakening of features and shifting of features to shorter wavelength. One important result is that the 2 µm feature is stronger in amorphous H2O-ice than it is in crystalline H2O-ice. We will also discuss the changes seen when H2O is mixed with other components, including CO2, CH4, HCN, and NH3 (Bernstein et al. 2005; Bernstein et al. 2006).

Abstract: In this contribution our attention is focused on physical properties related with the structure of some ices present in TNOs. The density and the real part of the index of refraction have been studied for molecules as CH$_4$, N$_2$ and CO$_2$, alone or in mixtures at different deposition temperatures. In experiments performed with mixtures, variations on sublimation temperature have also been studied. The used techniques depending on the experiment have been “dual-angle laser interference technique”, mass spectroscopy, and UV-Vis reflectance (200-850 nm). Results presented could be relevant because the reactivity of the icy surface may be dependent on its density (related with porosity) and/or other parameters. The composition of ices on TNOs and their temperature could vary depending on the object, then it is important to determine the dependence of the structure with both composition and temperature.
Abstract: In the present age of exploration for the outer solar system our knowledge of icy bodies in the Kuiper Belt is growing rapidly with new astronomical discoveries, while the heliospheric space weathering environment of these bodies is being measured in-situ by the Voyager 1 and 2 spacecraft. In December 2004 the Voyager 1 spacecraft first detected the solar wind termination shock at a distance of 94 AU and is now measuring the heliosheath region where the outward expanding solar wind begins to interact with plasma, neutral gas, and magnetic fields of the Very Local Interstellar Medium within 1000 AU of the Sun. Energetic particles accelerated at the termination shock, and in still-sought regions within the heliosheath extending tens of AU outward to the heliopause contact boundary with the VLISM, are dominant energy sources for top surface irradiation of all Kuiper Belt Objects. Orbits of some detected scattered disk objects pass through the heliosheath, in some cases far out into the VLISM, and the termination shock may occasionally move inward, in response to decreased solar activity and increased VLISM density, into the Kuiper Belt region. From inwards of the Kuiper Belt the solar wind plasma and associated energetic particles propagate outwards to provide additional energy sources for space weathering. Occasional large solar flare and coronal mass ejection events can dramatically increase the solar input. The 22-year magnetic cycle of the Sun affects, via the solar wind, the processes of energetic particle acceleration in the outer heliosphere, increasing or decreasing fluxes near the Ecliptic in the Kuiper Belt region. The Voyager 1 and 2 missions were launched from Earth in 1977 and provide a history of measurements moving continuously outward and extending over almost three full solar cycles. Comparison of the Voyager particle flux data with that from comparable long-term monitors near Earth at 1 AU, and semi-empirical models for extrapolation over the great distance from Earth to the Voyagers, provide the capability to potentially model the time-averaged fluxes of plasma and energetic particles across the full Kuiper Belt region. Improving knowledge of the heliosheath region will allow better extrapolations out into the VLISM beyond the heliopause. From these data, the heliospheric flux models, and available laboratory measurements for surface irradiation effects applicable to known objects, we will discuss the prospects for characterization of space weathering effects from ion irradiation for the different constituent populations of the Kuiper Belt. We will also review the relevant measurements for space weathering applications from the New Horizons spacecraft that will measure low energy ions and also the interplanetary dust environment out to Pluto and beyond into the Kuiper Belt within the next two decades.
SESSION : CHARACTERIZATIONS
Abstract title: Pluto: The First and Best Known Planet in the Kuiper Belt
Authors: A. Stern

Abstract: Pluto's discovery in 1930 presaged the discovery of the Kuiper Belt by over 60 years. Similarly, the discovery of its large moon, Charon, its smaller moons, its high surface albedo, its red color, its surface volatiles, and its orbit in the 2:3 Neptune MMR all presaged key attributes of other KBOs. I will review the current state of knowledge of Pluto and discuss in more detail how it relates to and informs us of the population of planetary-scale KBOs as a whole.
Abstract: In this presentation we report visible and near infrared spectra covering the 0.35-2.5 micron spectral range of TNOs 2005 FY9 and 2003 UB313, 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 these large TNOs are similar to that of Pluto, with an infrared region dominated by very prominent absorptions bands formed in solid CH4. At wavelengths shorter than 0.6 micron, the spectra are almost featureless and red, beeing 2005 FY9 as red as Pluto's spectrum and 2003 UB313 slightly bluer. The red color most likely indicates the presence of complex organics, as has been hypothesized for Pluto and many other TNOs. The icy-CH4 bands in these new giant TNOs are significantly stronger than those of Pluto, in particular in the visible, implying that methane could be even more abundant on its surface. The composition of the surface layers of both TNOs, in particular the possibility of the presence of N2 ice, is discussed based in the central wavelength of the methane-ice bands. 2005 FY9 and 2003 UB313 provide an exciting new laboratory for the study of processes considered for Pluto and Triton, including the possibility that these TNOs have an atmosphere comparable to Pluto's.
Abstract: The knowledge of the surface properties of the small icy bodies of the solar system are limited due to the intrinsic faintness of these objects and the lack of constraints (albedo surface roughness). Recently, observations carried out with SPITZER gave limits about albedo of several Trans-Neptunian Objects and Centaurs. We reanalyse the better quality available spectra (including visible and near-infrared range) using the albedo constraints and different radiative transfer models with different kinds of mixtures (geographic and intimate). These models are based on reflectances or optical constants of ices and organics components like ices, tholins and carbonaceous matter.
Abstract: We present near infrared and visible spectra of two TNOs, 2002 TX300 AND 2003 EL61 covering the 0.35-2.5 micron, 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 spectra of both TNOs resemble that of Charon: featureless and neutral in the visible up to 1.2 microns and dominated by very strong water ice absorption bands in the near-infrared at 1.5 and 2.0 microns. The similarity between (55636) 2002 TX300 and Charon was first pointed out by Licandro et al. (A&A in press), they remark that both spectra have neutral color in the visible and deep water ice absorption bands in the infrared, but unfortunately the S/N of the spectrum do not allow to determine if the water ice is amorphous or crystalline. On the other hand the observed bands are deeper than those in Charon which is indicative of a higher water-ice abundance and/or larger particle size in the surface of TX300 than in Charon. Trujillo et al.(2006, submitted) presented a high S/N near-infrared spectrum of 2003 EL61. It shows strong clear crystalline water-ice bands. We obtained and present infrared spectrum with a lower S/N but rotationally resolved and visible spectrum that confirm Trujillo et al.. We complete this study with the spectrum of 1996 TO66. In 1999 Brown et al. (AJ,1999) confirmed the first observation of water ice bands in the spectrum of a TNO. Photometry and spectroscopy in the visible showed that is has a neutral to blue color in this spectral region. Its complete VNIR spectrum has again similarities with that of Charon showing deep bands and will be also analyzed. A comparative study of these objects will be presented using mineralogical models based on the Shkuratov theory (Shkuratov et al, 1999). Finally, we discuss possible resurfacing mechanisms that keep the surface of these four TNOs so fresh, with such a big amount of water and such a low amount of organics.
Abstract: To investigate the evolution of the whole TNO population we have analyzed the results obtained by our group from the VLT-ESO programs together with all the spectroscopic data on TNOs and Centaurs available in the literature. The main results of the analysis on the whole sample of 32 objects (for which visible and near-infrared spectra are available) can be summarized as follows:

1) Non obvious trends have been found between the presence/detection of ice and the taxonomic groups (BB, BR, IR, RR), even if the BB group (objects with neutral/bluish spectra) seems to show more ice content on their surfaces, while the RR group (the reddest objects) seems to favour objects with no ice detection.

2) No relationship has been found between the presence of ice in near-infrared spectra and the orbital elements and/or dynamical classes, which could have implied a common origin.

3) All large objects (D < 700 km) show the presence of some ices on their surface. This implies that the space weathering and collisions/resurfacing are not the only mechanisms that can explain the surface properties and composition.
Abstract: 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. 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.

After the first polarimetric measurements of 28978 Ixion (Boehnhardt et al. 2004, A&A 415, L15) we present 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 our 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 %). A colour dependance of the polarization is not obvious from our measurements. The two TNOs show differing polarization curves: for Ixion, the negative polarization increases rapidly with phase; for Quaoar, the polarization is relatively small (-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.
Abstract: Ground-based observations of Kuiper belt objects are strictly limited by low phase angles (angle Sun-Object-Earth) giving an opportunity to reach extremely low values less than 0.1 deg. At sub-degree phase angles an exponential increase in brightness is typically observed for solid planetary surfaces. The increase can reach enormously large values equivalent to a phase slope of 1 mag/deg. This effect well-observed for bright asteroids and satellites was named as opposition spike (Harris et al., Icarus, 81, 365, 1989) to distinguish it from ordinary opposition effect characterized by wider and less steep increase in brightness toward zero phase angles. An opposition spike is usually attributed to be caused by the coherent backscatter enhancement due to constructive interference of rays in multiply scattering media. Its amplitude depends on surface albedo considerably decreasing for dark surfaces. However available observations of dark surfaces were typically obtained at the phase angles larger than 0.1 deg and a possibility of the narrower spike was not fully excluded.

We present results of first photometric measurements of laboratory samples down to extremely low phase angle of 0.008 deg. Such low phase angles become feasible due to small linear apertures of the light source (a laser) and receiver (photomultiplier Hamamatsu H5783-01) and the large distance from the light source and detector to the scattering surface (samples) that is 25 m. Two samples of similar structure but very different albedo (a smoked MgO and a carbon soot) were measured repeatedly at increasing and decreasing phase angles. Coincidence of these two dependencies is an indicator of the reproducibility of the measurements. The bright sample of MgO demonstrates a very prominent opposition spike at phase angles less than 0.8 deg. The dark sample of carbon soot do not show any opposition features; its phase curve is almost linear in the range 0.008 - 2 deg. On the other hand, if we consider a wider phase angle range 0.008 - 17 deg, the non-linearity of the carbon soot phase curve is clearly seen. This suggests that observations of opposition spike can put constraints on surface albedo. A surface showing a prominent spike inevitably has rather high albedo that is necessary to produce the coherent backscatter enhancement. 20000 Varuna is the first Kuiper belt object for which a pronounced opposition spike was well-measured down to phase angle of 0.05 deg (Hicks et al., Icarus, 176, 492, 2005; Belskaya et al. Icarus, 2006). For a few other objects there are indications on a possibility of such spike (e.g. Rousselot et al., Icarus, 176, 478, 2005). Thus, low phase angle observations give an additional evidence that Kuiper belt objects may have higher albedos than previously assumed.
Abstract: IRAS and ISO observations have shown that the Pluto-Charon system exhibits a thermal lightcurve, roughly but not exactly anticorrelated with Pluto's visible lightcurve (Sykes 1999, Lellouch et al 2000). Modelling of ISO observations at 60, 100, 150 and 200 micron indicated that Pluto's surface has a thermal inertia in the range (1.5-10)x10^4 erg cm^-2 s^{-1/2} K^{-1}, comparable to other icy satellites, and relatively high bolometric emissivities, although the 150-micron fluxes were found to be anomalously high. The Pluto-Charon system was observed by the SPITZER/MIPS instrument on 17-22 Sept. 2004, sampling eight longitudes on the lightcurve. Observations were obtained at 24, 70 and 160 micron. The main results are the following. Pluto-Charon is detected for the first time at 24 micron, with high S/N. The 24-micron is well in phase with the ISO 60-micron lightcurve, and its amplitude (as given by the ratio of maximum to minimum flux) is about 50 %, with a mean flux of about 7 Jy. A very preliminary comparison with the models of Lellouch et al. (2000) suggests a thermal inertia of ~5 x10^4 erg cm^{-2} s^{-1/2} K^{-1}. The 70-micron lightcurve has an amplitude of ~ 30 %, less than observed by ISO at 60-micron. Finally, the noisier 160-micron data do not clearly exhibit a lightcurve but show fluxes that are typically twice lower than the ISO 150-micron fluxes. We will present a modelling of these data in terms of thermophysical models of Pluto's surface, using multiple terrain models derived from visible and infrared spectroscopy and visible lightcurve information (e.g. Grundy and Fink 1996, Grundy and Buie 2001). We will attempt to derive improved values on the thermal inertia and emissivity of the various units.
Abstract: The primary motivation for studying the Kuiper Belt Objects (KBOs) is the belief that they are a window into the natal planet-forming environment shortly after the age of accretion. In terms of surface composition, many believe the KBOs are unique in harboring unaltered icy materials beneath their surfaces, whose signatures are primarily found via near-infrared spectroscopy. We are now in a position to test this long-held belief with the discovery and characterization of the brightest KBOs which has taken place in the past two years. Available spectra of the brightest KBOs will be reviewed to determine which spectra are of sufficient quality to place constraints on fundamental molecules of interest: methane, water, nitrogen, carbon oxides, ammonia compounds and other species. The high-quality KBO spectra will be compared with well-studied bodies: in-situ and remote observations of the largest icy satellites of the gas giants as well as the Pluto/Charon system. Of particular interest are the physical phase and quantity of possible volatile atmospheric components such as nitrogen and methane ice, as well as species that may indicate surface renewal such as crystalline water ice. The presence of these materials tells us whether the KBOs are indeed unique in the solar system in terms of their physical primordial nature.

We can now estimate our chance at detecting additional molecules in KBOs in the next few years through three main methods. First, performance of wide field surveys will be examined to estimate the number of as yet undiscovered bright KBOs that are likely to be found in the next few years. Second, known KBOs will be identified which have to date been insufficiently observed by the largest telescopes. Lastly, the latest instrumentation on major telescopes, in particular the use of laser guide star systems, will be examined to identify potential gains in signal-to-noise. For the first time, we have strong detections of ices on the largest KBOs, and we can estimate how many more such detections may be made.
Abstract: Thermal emission from a small but important sample of TNOs and Centaurs has been detected using the Spitzer Space Telescope (at wavelengths of 24 and 70um), and ground-based millimeter-wave observatories. These data provide most of the firm constraints we have on TNO and Centaur albedos and sizes. We report results from several Spitzer Space Telescope programs, in which we have observed 50 TNOs, and 14 Centaur objects. A significant fraction of the observations have produced non-detections, which in some cases provide useful lower limits on albedo and upper limits on size. A comparable fraction have resulted in detections at a single wavelength. Such observations weakly constrain albedo and size, because of large uncertainties in modeling the data. We have detected 15 KBOs, and nearly all of the Centaurs, at both 24 and 70um. These 2-band detections are particularly useful because they directly constrain the temperature of the surface: the albedo and size in this case is quite insensitive to the thermal model used, and their accuracy is limited only by the SNR of the data and the accuracy of the calibration.

We will focus on the overall success of these programs, discuss some of the special data processing techniques we have developed, and summarize the albedos and sizes we derive for those objects detected at 2 wavelengths. Other presentations will discuss results for individual objects in more detail.
Abstract: We have measured reflectances of a sample of Kuiper Belt Objects (KBOs), Centaurs, and low albedo Trojan asteroids with the infrared array camera (IRAC) on the Spitzer Space Telescope. As of the abstract deadline, 13 of the 30 objects in our program had been observed. IRAC measures broadband fluxes at 3.6, 4.5, 5.8, and 8.0 microns. Reflectance is measured for all 30 objects at 3.6 and 4.5 microns. Only a handful of TNOs and Centaurs are bright enough for the detection of reflected flux at 5.8 microns, none are detected at 8.0 microns. For the low albedo Trojan asteroids, the flux at 5.8 microns is a combination of reflection and emission, whereas the 8.0 micron flux is dominated by thermal emission. We have also observed Pluto at eight different longitudes in all four IRAC bands during its 6.387 day rotation. Ground-based spectra have previously been published from the visible to 2.5 µm for all objects in the target list. In some cases, particularly for the featureless spectra, spectral models admit a range of possible compositions. Reflectances in the IRAC bands allow discrimination between these possible spectral models, thereby constraining surface compositions. For objects whose vis-NIR spectra show specific absorption bands (e.g., H_2O), the IRAC data permit refinement of the spectral interpretations. For example, the vis-NIR spectrum of 8405 Asbolus is featureless, with a moderately red spectral slope. The IRAC data exhibit no absorptions in the 3.6 and 4.5 micron bands, with perhaps a slight downturn in the 5.8 micron band. These additional measurements indicate no H_2O on this surface and limit the materials that could be responsible for the vis-NIR spectral properties. The IRAC data of 50000 Quaoar, on the other hand, show evidence for H_2O absorption, as expected from the bands detected at 1.5 and 2.0 microns previously, though slight refinement of the surface model is necessary to properly fit the new data points. We will present these new data and implications for the compositions of the individual objects thus far observed.
Abstract: From the standpoint of their composition KBOs and Centaurs are still a puzzle: some of them contain water ice, some methane ice, some are rich in pyroxenes and or olivine, and some contain a reddening agent that, we think, has to be organic in nature. Overall it is still a puzzle whose pieces are slowly coming in with the advent of space telescopes and spacecraft. Recent data from the Spitzer Space Telescope have started providing more and more pieces to the puzzle. Even though the data are only sparse photometric measurements they still provide information on the overall shape and brightness of the spectrum, and sometimes on the presence of strong features, signatures for water ice and or methane ice.

In a previous work we presented new models for a set of KBOs whose overall albedo had been revised by new Spitzer measurements. All of our objects ranged in albedo from faint and constant through the visible and near-IR spectrum to bright and ascending in albedo going from the visible towards the IR. Their composition, however, seemed to differ only in the overall amount of reddening component along with a mineral component that varied from pyroxene (Mg-rich) to serpentine going from the highest to lowest albedo.

This work adds a few more objects with new Spitzer albedos, some previously studied, some new to our sample. We present new models calculated with the Shkuratov code, making use of Imanaka’s new optical constants for Titan Tholin as well as Khare’s. Results are compared to previously studied objects from the Spitzer sample to look for possible trends in composition.
Abstract: It is known for a long time that the brightness of planetary surfaces significantly changes with phase angle (angle Sun-Target-Earth). These functions present typically an opposition effect, i.e. a sharp increase of the brightness when phase angle approaches zero. Two main physical processes are considered to be responsible for this phenomenon, namely shadow hiding and coherent backscatter enhancement. Their relative contribution depends on surface properties of a top layer, mainly on its albedo and porosity. An opposition effect phenomenon plays a dominant role in magnitude-phase curves of Kuiper Belt objects since they can be observed only at small phase angles. Their study can provide important constraints on physical properties of the upper surface layer of KBOs.

We have used already published data (either as phase curves or as photometric data), as well as our own observational data to construct the phase curves for about 20 different Transneptunian Objects or Centaurs. These phase curves were fitted in the same way to quantify the opposition effect values. Phase curve slopes were derived in the same phase angles range. This permits to compare the steepness of the phase function curve for the different targets. The correlations obtained when using these slopes and different physical and orbital parameters - such as albedo, dynamical class or colors - will be discussed.
Abstract: Through a dedicated Neptune Lagrangian survey we have discovered three Neptune Trojans, quadrupling the known population. The main survey results include the discovery of the first known high inclination Neptune Trojan, 2005 TN53. Our survey allows us to estimate the Neptune Trojan inclination and population distribution. Through these results we put constraints on the possible formation and capture mechanisms of the Neptune Trojans. In addition we have observed the Neptune Trojans surface properties for the first time allowing them to be compared to other small body populations in the solar system including the nearby Kuiper Belt objects. Only now with our increasing knowledge of the Neptune Trojan numbers, orbits and physical properties are we starting to get a glimpse at these objects formation and evolution. This also gives us insight into the planet formation and migration process. We will discuss the results we have obtained from the analysis of our observations. This work is currently in press.
Abstract: On this third lustrum since the discovery of the first Trans-Neptunian Object (TNO) the study of the Edgeworth-Kuiper Belt (EKB) as seen an outbreak of discoveries restating itself as one of the most active areas of research in Astronomy.

Since the first photometric studies on this field it was evident that TNOs and Centaurs exhibited dramatically different visible surface colors (i.e. spectral reflectances), ranging from neutral to very red. Such diversity is also seen with the more recent near-IR color surveys. Regardless of the rapidly growing knowledge of surface spectra for Centaurs and TNOs, presently, multicolor photometry is the only statistically relevant characterization of surface properties of Centaurs and TNOs, and several of their sub-populations are still under-sampled or basically unknown.

Both populations are characterized not only by their colors but also by their orbital parameters, which also reveal a wide variety. Identifying the interconnections between these variables is a starting point to the understanding of the reasons for such diversity and the physical processes involved. Analysis of correlations is the most fundamental tool to study the interconnection between two or more variables. These correlations may be confronted with prior theoretical predictions and lead to new theoretical and observational/experimental works.

We will discuss the use of several different correlation coefficients, the influence of data with error bars, the estimation of confidence intervals, the identified correlations between surface colors and orbital parameters, and how they relate with our current understanding of the Edgeworth-Kuiper Belt.
Abstract: We report near-infrared spectroscopic observations of the binary TNO system 2003 EL61. The object 2003 EL61 is a large TNO with two satellites. The brighter satellite orbits around the primary in 49.1 days, and its semi-major axis is 49,500 km and the eccentricity is 0.05. Its total mass is 4.2x10^{21} kg and satellite to primary mass ratio is about 1/100 assuming that the satellite and the primary have the same albedo and density (Brown et al. 2005). The diameter of the primary and the satellite will be 1700 km and 380 km if the density is 1.5x10^3 kg m^{-3}.

We observed 2003 EL61 using Subaru telescope with IRCS on UT 2006 Jan. 15. The spectrograph covers wavelength range from 1.44 um to 2.54 um simultaneously. The slit was aligned to the proper motion of the primary. Since the position angle of the satellite happened to be close to the direction of the proper motion, we could obtain spectra of the primary and the satellite simultaneously. The separation between the satellite and the primary was 1.0 arcsec.

The spectra of both the primary and the satellite show water ice absorption bands near 1.5 um and 2.0 um, and relatively narrow absorption feature at 1.65 um that indicates the ice is crystalline. No other absorption features, including ammonia hydrate, are seen with high confidence level.

Crystalline water ice is formed at >100K or by slow deposition of water vapor. The crystallization can occur by current micrometeorite bombardments or global heating at the satellite forming phase. On the other hand crystalline water ice is destroyed (change to amorphous ice) by the impact of high energy particles or UV radiation. Although we know little about the environment of TNO region, we roughly estimated the balance of crystallization/amorphization using currently available data. We will discuss the origin of the observed crystalline water ice on the satellite.
Abstract: J-M band spectroscopic observations of Pluto and Charon were obtained during 2005 August 4 - 7 UT using the NACO instrument at VLT UT4 on Cerro Paranal. The usage of the adaptive optics capability of NACO allows to separate the spectra of this binary (distance < 0.75") as well as it increases the signal-to-noise ratio of the objects and it reduces the sky background due to the small pixel scale (0.27"/pix). The slit acquisition images of the Pluto-Charon spectroscopy were taken in K band and, although of short total integration time, they allowed to perform a search for the newly discovered moons P1 and P2 in the Pluto-Charon system. The paper will present the results of the on-going analysis of these observations.
Abstract title: Spitzer/MIPS Survey of Dynamically Cold KBOs
Authors: W.M. Grundy(1) J.A. Stansberry(2) J.R. Spencer(3) L.H. Wasserman(1) E.I. Chiang(4)
M.W. Buie(1)
Institute/s: (1)Lowell Obs. (2)Univ. Arizona (3)Southwest Research Inst. (4)Univ. California Berkeley

Abstract: The early dynamical churning that left today's Kuiper belt as its fossil remnant seems to have shuffled together objects deriving from more than one compositional reservoir, as evidenced the broad ranges of colors and albedos observed (e.g., Peixinho et al. 2004; Grundy et al. 2005). Different dynamical classes of TNOs show similar distributions of colors and albedos, frustrating attempts to study compositional zoning in the outer protoplanetary nebula by comparison between dynamical classes.

However, one class may have escaped the worst of this mixing. Classical KBOs occupy near-circular, non-resonant orbits concentrated between 40 and 48 AU. Evidence is emerging that the Classical KBOs consist of two overlapping sub-populations (Elliot et al. 2005), a dynamically "hot", higher inclination population with the usual wide range of colors, and a dynamically "cold" population with low inclinations, consisting predominantly of red objects (e.g., Trujillo and Brown 2002; Tegler and Romanishin 2000, 2003). Dynamical arguments and color photometry both suggest that Cold Classical KBOs (CCKBOs) may be the most likely sub-population to preserve some memory of their primordial locations in their present-day orbits. Accordingly, these objects are particularly interesting targets for physical studies, as they can potentially shed light on the chemistry of the outer parts of the protosolar nebula.

Unfortunately, observing CCKBOs is especially challenging. Even the brightest examples are frustratingly faint compared with the brightest members of other dynamical classes, in both reflected light and thermal emission.

We are observing a sample of dynamically "cold" and "hot" Classical KBOs using the 24 and 70 micron channels of MIPS on the Spitzer Space Telescope, in an effort to learn more about the physical properties of CCKBOs, and to search for possible systematic differences between them and objects from other dynamical classes. Our observing strategy takes advantage of these objects' slow motion against the sky plane. By spreading observations over multiple visits, we can push well beyond the background confusion limits that affect observations of fixed targets or single epoch observations. Even so, some targets are not detected at all, or are only marginally detected in one or more wavelengths. In conjunction with ground-based visible wavelength photometry, the Spitzer observations enable us to put some crude limits on the sizes and albedos of these elusive targets. The observations will be completed by summer 2006 and final results from this survey will be presented.
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Abstract title: Discovery of Cometary Activity on Centaur 174P/Echeclus  
Authors: Young-Jun Choi, Paul Weissman  
Institute/s: Jet Propulsion Laboratory

Abstract: We report the first detection of cometary activity on Centaur 174P/Echeclus. Numbered Centaur (60558) 2000 EC98, its previous designation, originally classified as an asteroidal body with no visible sign of coma or non-rotational photometric variations, was discovered to be having a massive cometary outburst on 2005 December 30.50 UT, using the Palomar 5-m reflector (+Large Format Camera). The coma had a total magnitude R = 15.0 and extended 20 arc-seconds from the nucleus condensation, equivalent to a projected distance of 180,000 km. The magnitude of the bare nucleus was expected to be only R ~ 21.0. We will present images of the well-defined coma structure showing a major jet, and surface brightness and color profiles as a function of radial distance from the nucleus. Dust production rates, comparison with the other Centaur objects, and a historical investigation into 174P/Echeclus's activity will be discussed. This work was performed in part at the Jet Propulsion Laboratory under contract with NASA, and was supported in part by the NASA Planetary Astronomy Program.
Abstract: 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.
Abstract: On December 30, 2005, Choi and Weissman discovered that the formerly dormant Centaur 2000 EC98 was in strong outburst (IAUC 8656, 2006). Previous observations spanning a 3 year period indicated a lack of coma down to the 27 mag/sq. arcsec level (Rousselot et al. 2005). We present Spitzer MIPS observations of the newly active Centaur 60558 Echeclus (2000 EC98), also now designated 174P/Echeclus, taken in late February of this year. The images show strong signal at both the 24 and 70 micron bands, and reveal an extended coma on the order of 2 arcmin in diameter. Simultaneous visual band observations were also made with Palomar Observatory's 200 inch telescope, and Table Mountain Observatory's 0.6m, and those results will also be discussed. This work was performed in part at the Jet Propulsion Laboratory under contract with NASA, and was supported in part by the NASA Planetary Astronomy Program.
Abstract: Over the past year we have conducted a survey of icy planetoids in the Kuiper belt using multiple instruments to probe their chemical and physical states. The aim of the survey is to create as complete a description of this class of objects as possible. Here we discuss our spectroscopic data that were obtained as part of this survey. Visible spectra were obtained at Palomar Observatory and near-infrared spectra from 1.0-2.5 microns were obtained at the Keck Telescopes. A variety of colors and some mineralogical features are seen in the visible spectra. In the near-IR, most of the largest KBOs show strong spectral features due to methane and appear similar to those seen on Pluto. Other objects have absorptions characteristic of crystalline water ice, indicating recent reworking of the surface, while some KBOs appear to be spectrally featureless. The variation in spectral features indicates a number of competing processes are active in shaping the surfaces of the largest Kuiper Belt Objects. We will discuss several of these processes and trends in the spectra with albedo, size, and color.
Abstract: It has been recently suggested (Morbidelli et al. 2005 Nature 435, 462) that Jupiter Trojans, Kuiper belt objects and the scattered disk, originated in the planetesimal disk which drove the planetary migration. In this scenario the comparison among the physical properties of Trans-Neptunian Objects (TNOs), Centaurs, and Jupiter Trojans, can help us to investigate the nature of the primordial population of small bodies of the outer Solar System and the mechanisms which altered its original characteristics.

Color indices, surface composition as resulting from the analysis of visible and near-infrared spectra, and albedo values are diagnostic characteristics which allow us to investigate the nature of the bodies of the Solar System and to infer information about their origin and evolution. The surface composition, and in particular the presence or the lack of spectra features related to the presence of ices on the surfaces of members of the different populations, such as their albedo values, can give some hints on the processes which altered the surfaces of these bodies, the thermal gradient they experienced and/or the weathering processes they suffered.

We will present an analysis of these characteristics for TNOs, Centaurs and Jupiter Trojans, and, by a comparison among them, we will outline a picture of the possible composition and the evolution of these bodies of the outer Solar System.
SESSION : POSTERS
Abstract: For the simple systems, the resonant equations of motions, which are based on the Lagrange's Planetary Equations, can be transformed into a pendulum model. We set up a generalized pendulum model which can investigate the influence of a non-Keplerian perturber on the resonant orbits. The results of the phase-plane analysis of these models will be used to compare with the simulations.
Abstract title: NIR spectroscopy of (59358) 1999 CL158: Probing the Irradiation - Collisional resurfacing model
Institute/s: (1) Observatorio Nacional, (2) Instituto de Astronomia y Fisica del Espacio, (3) Queen Mary and Westfield College

Abstract: The physical surface properties of a Kuiper Belt object is the result of interplay between irradiation from the different kinds of cosmic rays and its collisional history. Objects that have undergone a recent-major collision will very likely have physical properties that are very different from those of the bulk population. In particular, pristine ices from the interior are expected to be present on the surface.
We have determined that (59358) 1999 CL158 has resided near its location for no more than 7 Myr. Therefore, it is the strongest candidate to have undergone a major and recent collisional event in the whole trans-Neptunian population. This study will help us to understand the interior composition of the whole trans-Neptunian population and also that of the short period comets.
We obtained on March 2006 a near-infrared spectrum of (59358) 1999 CL158 using the near infrared imager and spectrograph, NIRI, at Gemini north 8-m telescope in the region between 1.43 - 1.96 microns. In the present work we will present the result of the analysis of this data, in particular the search of ice bands, such as CH$_4$. 
Abstract: The poster presents the results of investigation of dynamical behaviour of objects from the Kuiper belt after their collisions with small bodies moving on model orbits similar to the Kreutz cometary orbits. The study was motivated by the idea that the Kuiper belt is a source of short-period comets.

One of the possible nongravitational forces that can change a near-circular orbit of some Kuiper object to an elliptical one, typical of short-period comets, is the collisional force. The orbital velocity of a comet from the Kreutz group with a near-parabolic orbit in the region of the Kuiper belt is only somewhat higher than 1 km/s. Therefore, the change of the velocity of a target Kuiper object by such collision cannot exceed this value.

In our study we used model orbits of the Kuiper belt objects with different values of the eccentricity and semi-major axis and studied their orbital behaviour after the collision which changed their orbital velocity by not more than 1 km/s. Depending on the change of the orbital velocity vector, the object will migrate to inner or outer part of the solar system. The TNO's object 90482 Orcus, as the real one, was used for similar modelling of the studied migration mechanism.
Abstract: The presence of methane on four of the largest Kuiper Belt Objects (2003 UB313, Pluto, 2005 FY9 and Sedna) is unexpected. Methane is rapidly destroyed by UV photolysis and lost due to atmospheric escape. The total amount of methane on the surface of Pluto should be depleted by atmospheric escape in only 3 million years (Traffon et al. 1997). Interior reservoirs of primordial methane are unlikely to completely account for its current presence on large Kuiper Belt Objects. In the case of Pluto, even if it retained all of its primordial methane, which is unlikely due to volatile loss during accretion and differentiation, the total amount of methane lost from hydrodynamic escape over the age of the Solar System is still greater than or equal to its initial mass of methane. Similar arguments can be made for the other Kuiper Belt Objects with methane. Thus a methane production mechanism is necessary to account for its current presence on these objects. We will discuss such production mechanisms and the implications they have on the interiors structures of these bodies.
Abstract title: A combined stellar-Neptune perturbation of outer Kuiper belt and its outer border at 50 AU
Authors: Neslusan L., Paulech T.
Institute/s: Astronomical Institute, Slovak Academy of Sciences, Dubravska cesta 9, 84228 Bratislava, Slovakia

Abstract: Through a numerical integration of the orbits of test particles representing small bodies in the outer region of once existing proto-planetary discs, we examine a possibility that the observed truncation of the classical Kuiper belt at 50 AU was caused by a close encounter of the Solar System with a star. We consider a spectrum of possible geometries and masses of the perturbing star, whereby the simultaneous perturbation by the Neptune is also taken into account. A minimum decrease of the number density of the bodies beyond 50 AU, necessary to explain the truncation, is determined on the basis of the survey conducted by Trujillo et al. (2001, Astron. J. 122, 457), within which the largest number of the trans-Neptunian objects have been discovered, till now. We consider the part of this survey at the ecliptic, where approximately 58 classical Kuiper-belt objects (CKBOs) were discovered (the number is not exact, since several objects are not classified and a fraction of CKBOs among them is only estimated). Though the stellar perturbation tends to increase the relative number density of the CKBOs inside 50 AU in some cases, the Neptune simultaneously reduces, again, this number density. The ratio of the discovery probabilities of CKBOs within 50 AU and beyond this distance approaches to a necessary minimum ratio for some combinations of the stellar orbital parameters and masses. However, even these interesting combinations are not acceptable, because the corresponding change of the velocity of Sun is so large that the Oort cloud would have been stripped and no dynamically new comets could be observed. In conclusion, no stellar encounter could cause the truncation of the Kuiper belt after the macroscopic bodies in the belt and significant fraction of the Oort cloud formed.
Abstract: Evidence for the presence of hydrated silicates was reported at the surface of two Plutinos, (38628) Huya and (47932) 2000 GN171 (Lazzarin et al 2003, de Bergh et al 2004). The large absorption features observed around 700nm in 2001 were not detected in their data from 2002. However, the rotational state of these objects is not known in good enough details to determine if a different portion of the surface was observed and if the objects surfaces are truly heterogeneous. If this detection is confirmed, it puts strong constraints on the thermal history of the Kuiper Belt. The formation of hydrated silicates implies either the presence of liquid water (in the 273 - 400K range) at some point of the objects history or the presence of a rock/ice interface at 200 - 273 K. Both processes are not expected to occur routinely in the Kuiper Belt region. To tackle this question, we reobserved this two Plutinos in visible spectroscopy with Keck2 + LRIS-B, as well as looked for large absorption features on other KBOs. In this paper, we will present the results and discuss their physical implications.
Abstract: The discovery of the planetoid Sedna in a distant orbit well beyond the planetary region defies current understanding of the formation of the solar system (BTR2004). Several scenarios can explain the present-day orbit of Sedna. These possible scenarios include: 1. Scattering by an undetected Mars-mass planet in a circular orbit at 70 AU (BTR2004). 2. Capture from the Kuiper belt of another star during a stellar encounter early in the solar system's history (KB2004). 3. Scattering by a single extremely close stellar encounter of a specific geometry (BTR2004). 4. A large series of slower more distant stellar encounters, as would occur in a dense cluster birth environment, could also raise the perihelia of highly eccentric objects (BTR2004). Each of these scenarios has profound -- and profoundly different -- implications for our understanding of the solar system and its formation, and each of these scenarios predicts a very different population of distant objects in the outer solar system.

The apparent motion of these objects will be significantly slower than traditional Kuiper belt objects, and slow enough (<1.5"/hr) to be missed by most traditional KBO searches that look for motions in images taken an hour apart. In the past year we have conducted an initial 36 night search for objects in distant Sedna-like orbits using the Palomar Hale 5-m telescope. Our survey is sensitive to objects as faint as R=24.0 and moving as slowly as 0.04"/hr. Thus far we have found no new Sedna-like objects.

Abstract: The discovery rates of transneptunian objects (TNOs) increase in recent years. Such results call for further astrometric data to refine their orbits. It means both follow-up astrometry and search for archive images to measure prediscovery images. Several newly discovered transneptunian objects are brighter than magnitude 22 V, which is the limiting magnitude of images taken by the 1.06-m KLENOT Telescope at the Klet Observatory. The KLENOT telescope was put into operation in March 2002 as a telescope dedicated especially for follow-up astrometry of unusual asteroids and comets. The KLENOT archive contains about 30,000 images up to now. Therefore we decided to increase our astrometric work to the past, exploit this archive and start a small TNO precovery survey using the KLENOT archive images. We show the system of KLENOT archive and discuss our methods used for precoveries. We also present the first results of this KLENOT TNO precovery survey, especially precovery data for 2005 FY9, which helped to establish reliable orbit for one of the brightest object in the Kuiper belt.
Abstract title: Thermodynamic behavior of small bodies during the collisional evolution of the Edgeworth-Kuiper Belt
Authors: Ulysse Marboeuf, Jean-Marc Petit and Olivier Mousis
Institute/s: Observatoire de Besancon

Abstract: Kuiper Belt objects are among the most primordial objects of the outer solar system. While their present-day composition is expected to be similar to that of primordial planetesimals produced in the outer solar nebula, it could have been substantially modified by the heating induced by high collision rates in the early Edgeworth-Kuiper Belt.

We used a cometary nucleus model derived from Espinasse et al.(1991), accounting for collisional energy input, a-la Orosei et al.(2001) to predict outgazing during the Deep Impact collision with 9P/Tempel 1 (Mousis et al. 2005).

We are modifying the model to make it numerically stable in cases of large collisional energy input (Orosei et al. 1999) and include several gasses, dust and a more refined treatment (including better knowledge of trapping) of the different phases of water ice. With this model, we will show the thermodynamic evolution of a KBO that are induced by collisions with a range of frequencies and kinetics energies compatible with those envisaged in the early Edgeworth-Kuiper Belt.
Abstract: We have searched for evidence of a dust coma around three Centaurs ((60558) 2000 EC98 (now 174P/Echeclus), 2000 FZ53 and 2000 GM137) and two Transneptunian Objects ((28978) Ixion and (29981) 1999 TD10). Previous observation of 2000 GM137 at 3.5-m NTT in 2001 had lead to a possible detection of a very faint coma (Rousselot and Petit, 2001). In order to confirm that detection, a new data set has been collected with the 8-m VLT in 2003. It does not show evidence of cometary activity.

The other objects, observed with the 3.5-m NTT and the 8-m VLT telescopes, do not present any evidence of cometary activity. This is the case for 174P/Echeclus despite the recent discovery of its cometary activity (Choi et al., 2006). Because of the absence of observable coma, upper limits for the Afrho parameters and dust production rates are presented.

References:
Choi Y.J., Weissmann P.R., Polishook D., 2006, IAUC 8656
Abstract: The modeling of internal evolution of cometary bodies takes into account various heat sources, such as insolation, crystallization, collisional effects and radioactive elements. In terms of composition, these models deal with a composition of dust and a mixture of volatiles, this may be either in solid or gaseous state. In terms of structure, the negligibility of self-gravity is taken as a general rule for all cometary bodies. Thus, a porous solid matrix filled with various volatiles (gaseous or solid) is the most common picture for a cometary body. As a result of the above assumptions, the equations that govern the structure and evolution are those of mass and energy conservation. A prescribed density profile usually replaces the demand for momentum conservation.

The negligibility of self-gravity, compared to the material strength, is amply justified for small bodies. However, large bodies (~100 km and larger) do not necessarily comply with this rule, at least not as a whole. Considering some various conjectures, regarding the compositional and structural properties of KBOs, we show that hydrostatic balance may play an important role in the evolution of internal structure in large bodies, affecting compaction and the continuous redistribution of pore sizes. We combine in our models the thermal processing of volatiles, due to the radionuclide 26Al (the most potent, for the timescale of evolution) and insolation (which is negligible for the orbits of most KBOs), with a hydrostatic scheme for the solid matrix.

Some model results for the internal structure and composition of KBOs, in terms of temperature, volatile abundance, possible water retention, porous structure and amorphous/crystalline ice stratification.
Abstract: We report rotational parameters of eight TNOs and Centaurs. These are the latest results obtained in the frame of our program devoted to derive rotational parameters of the brightest TNOs and Centaurs from Sierra Nevada Observatory (IAA-CSIC, Granada, Spain). We have compiled the rotational parameters of all the TNOs and Centaurs found in the literature obtaining a set of 70 objects. The current number of objects with known rotational parameters allows us to start a study to look for the existence of correlations between lightcurves amplitudes/spin periods and orbital elements. The results of this study will be presented.
Abstract: We present and discuss for the first time series observations of Prospero, Stephano, Setebos and Trinculo, four faint irregular satellites of Uranus, carried out at VLT, ESO Paranal (Chile) in July 2005. At the same time we present new observations of the brighter satellite Sycorax, which we had already observed before with NTT at ESO La Silla in 2000, to derive a new independent set of data with the aim to understand some discrepancies reported in the literature for this satellite's colors. Sycorax displays a variability of about 0.07 mag larger than previous observations but with a period in agreement with our previous determination.

Prospero exhibits a period of 4.6 hr and an amplitude of 0.21 mag. The impact of such a sizeable amplitude on the models of formation of Uranus and its irregulars has been throughly discussed in Parisi et al. (2006) a short resume is reported here.

For Setebos, Stephano and Trinculo, the present data do not allow us to derive any unambiguous periodicity. The colors we derive are in marginal agreement with previous studies on the subject.
Abstract: In the study of the final stages of planetary formation, one effect that has been ignored until recently is photophoresis. During the period that the nebula becomes optically thin enough for particles to see the proto-Sun, but still has a reasonable gas content, the photophoretic force acts to push dust grains outward. This provides a mechanism to transport silicaceous material from the inner Solar system to the regions in which the comets were forming. Further, the dust driven outward in this manner will eventually reach a region where the gas pressure is so low that the combined outward forces of radiation pressure and photophoresis balances the inward effects of gas drag (as opposed to closer in, where photophoresis and radiation pressure would be more effective than gas drag). For a given nebula model, this leads to a 'pile-up' of dust at around 50 Au (with size differentiation such that larger particles are stable closer to the Sun than their smaller brethren). Finally, as the gas continues to disperse, the equilibrium point moves back inward, reaching a distance of around 30 Au before the nebula is wholly dissipated.

Such a process would lead to an influx of silicates in the region of the forming Edgeworth-Kuiper belt, which could, effectively, result in 'dust-loading' of these bodies. Comets which had already been ejected from the regime of the outer planets into the Oort cloud could, conceivably, have missed this excess dust. Any comets still forming in the Outer Solar system (between Jupiter and Neptune) during this period would, of course, be swept by this outward moving dust belt, but would presumably acquire less dust than those in the 30-50 Au range, where the belt reaches its temporary equilibrium. This model suggests that comets which originate in the Edgeworth-Kuiper belt should be observed to contain some fraction of material which formed well within the ice-line (such as the crystalline silicates), along with suggesting that a fraction of Oort cloud comets (in particular those ejected early on) should contain a much smaller mass-fraction of such material. The existence of Olivine and CAIs in the ejecta from Comet Wild 2 (found by the Stardust mission) can easily be explained by this model. Also, photophoresis offers an alternative explanation for the measurement of a surprisingly high dust/ice ratio in Tempel 1 (from the Deep Impact collision) - if objects in the Edgeworth-Kuiper belt suffered the proposed dust loading, this could easily contribute to such a dust excess.
Abstract title: ESO-VLT observations of Charon and large TNOs with SINFONI: An analysis of their surface composition
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Abstract: We have used SINFONI, the new Adaptive Optics (AO) assisted spectro-imaging instrument at ESO-VLT, to obtain near-infrared reflectance spectra of the surface of Charon and the large Trans-Neptunian Objects (TNOs) 2003 UB313, 2003 EL61 and Sedna. In the case of Charon, the observations were carried out in AO mode using Pluto as reference for the wavefront analysis. The observations of the large TNOs were obtained under good seeing limited conditions (seeing ~ 1"). Charon was observed at several orbital phases in order to explore the spatial distribution of ices across its entire surface. In addition to obtain a precise inventory of the icy material present on Charon, the main motivation for this program was to investigate the nature of the 2.21 micron bands previously reported in the literature (Brown and Calvin 2000, Buie and Grundy 2000, Dumas et al. 2001), and tentatively attributed to ammonia hydrate. A preliminary analysis of these data support a rather homogeneous distribution of this ice over the surface of Charon. Although the TNOs data are still being analyzed at the time of writing, we can already report that spectral analysis based on Hapke models for bi-directional reflectance of solid ices (geographical and intimate mixtures) applied to the HK-band spectra obtained for UB313 confirm the strong methane ice bands previously reported by Brown et al. (2005). The possible presence of other icy compounds such as N2 and water ice is still under investigation. We will present at the meeting a detailed summary of the modeling results obtained for all the objects we observed.
Abstract: We present the latest results of the Meudon Multicolor survey. This survey aims at characterizing the colors properties and trends of Centaurs and Trans-Neptunian Objects. We report in this presentation IJHK photometry of objects obtained with CFHT-IR at the Canada-France-Hawaii 3.8-m Telescope (CFHT, Hawaii) and with INGRID at the William Hershel 4.2-m Telescope (WHT, La Palma). Combined with our previous visible colors, we have obtained quasi simultaneous visible-near-infrared colors for about 50 objects. This large sample allows an extended characterization of the colors properties of these primitive objects from the B (0.4 microns) to the K (2.2 microns) regime. A complete analysis of these results will be presented and discussed.
Abstract: By the end 2005 there were over one thousand discovered objects in the transneptunian or the Centaur region. Almost half of them have short observed arcs that makes a reliable orbit determination difficult, therefore orbit determination methods based on the statistical evaluation of uncertainty are better suited for analyzing these populations. We have applied the statistical ranging method to the sample of discovered objects. For every object we obtain a set of ~ 2000 orbits that samples the 6D probability density function (PDF) in the orbital-element phase space. Short-arc orbits present a particular pattern in the 3D space representation of the set of solutions (a "butterfly"-like pattern), that can be explained by analyzing the discovery circumstances. The individual PDFs are added to obtain the joint PDF of the distribution of known objects in the Centaur and Transneptunian population. Projections of these 6D PDFs into different sets of elements are presented in order to classify the objects in different dynamical classes. We analyze the characteristics of the orbital solutions for individual objects with peculiar features: objects in mean motion resonances with Neptune, unstable orbits in the short term, retrograde and Halley-type orbits (Damocloids), objects in the outer belt and in decoupled orbits.
Abstract: We present near-infrared spectra of Centaurs covering the range between 0.8 and 2.2 microns. These observations were obtained in the framework of a Program on “Physical Studies of TNOs, Centaurs and comet nuclei” carried out with the 3.58 m Telescopio Italiano Galilei in La Palma, Spain. Our objects are, (73480) 2002PN34, 32532 Thereus, 845 Asbolus, 31824 Elatus, 52872 Okyrhoe and two centaurs with observed activity 167P/Cineos and 95P/Chiron. We fit mineralogical models based on the Shkuratov Theory (Shkuratov et al,1999) to the reflectance with the aim of obtaining information on the surface composition "as a try to understand more about the surface composition of these objects and the possible relationship between these populations."
Abstract: Modern spectroscopic observations of Trans-Neptunian Objects are providing insights to surface composition and evolution of these objects. However, because TNOs are dark and distant, the data are usually rather noisy and the presence and characteristics of absorption features is often difficult to assess. A similar situation occurs with recent resolved spectra of Main Belt Asteroids, where spectral features hardly stand out of the noise.

We present here a new method based on wavelet decomposition and on a multiscale vision model, partly derived from image analysis techniques (e.g., Starck et al. Ap. J. 1997). This method was originally developed to process large imaging spectroscopy data sets from space borne instruments, and to extract the relevant information from highly correlated data, where it only represents a small fraction of the overall variance. The outcome of the analysis is a description of the bands detected, and a quantitative and reliable confidence parameter. The bands can be described either by the most appropriate wavelet scale only (for rapid analyses) or after reconstruction from all scales involved (for more precise measurements). An interesting side effect is the ability to separate even narrow features from random noise, as well as to identify low-frequency variations i.e., wide and shallow bands.

The principle of the method is presented here, and it is tested on simulated reflectance spectra of ices (H₂O, NH₃, CH₄, CH₃OH, N₂). The techniques is then applied to NIR spectra of Trans-Neptunian Objects and Main Belt asteroids, including recent observations of Sedna and 1 Ceres at the VLT. In both cases, the robustness of the method allows to identify and characterize spectral features in these very low signal-to-noise situations.
Abstract: The visible spectra of Trojan asteroids are similar to those of comet nuclei (e.g., Jewitt 2002). In this work, we compare new and published near-infrared spectra of comet nuclei with those of Trojan asteroids. We find that the spectral diversity among Trojan asteroids is comparable with that seen among the few comet nuclei observed so far in the near-infrared. We also found that the near-infrared spectra of Trojan asteroids 1143 Odysseus and 2797 Teucer (Emery and Brown 2003) resemble closely the spectrum of the nucleus of comet 162P/Siding Spring (Campins et al. 2006). In other words, among Trojan asteroids we find reasonable matches to individual comet spectra as well as to the spectral range observed so far among cometary nuclei. While we must understand surface evolution as well, such similarities suggest that the formation environments of both populations may have been analogous, as proposed by Morbidelli et al. (2005) based on dynamical arguments.


Emery, J. P., Brown, R. H. (2003) Constraints on the surface composition of Trojan asteroids from near-infrared (0.8-4.0 \( \mu \)m) spectroscopy. Icarus, 164, 104


Abstract: Early advances in understanding the hydrogen atom spectrum were driven by importing methods of celestial mechanics into atomic physics. The advent of quantum mechanics led to a divergence between classical and quantum mechanics. Recently, classical (and semiclassical) methods have experienced a revival and rely on using classical insights to predict quantum consequences. We discuss atomic analogs of the Trojan equilibria in atoms, molecules and quantum dots.
Abstract: Density information provides our only available window into the porosity and interior composition of KBOs for the foreseeable future. Estimated densities of comet nuclei, probably derived from the Kuiper Belt, are often low (e.g. 0.6 g cm\(^{-3}\) for SL9, Asphaug and Benz 1996), implying large porosities, but comet nuclei are much smaller than observable KBOs (< 10s of km in diameter). At the other extreme, known densities of large (>1000 km diameter) KBOs reach 2.03 g cm\(^{-3}\) for Pluto (Buie et al. 2006) and ~3.0 for 2003 EL61 (Rabinowitz et al. 2006). Saturn's moon Phoebe, only 200 km in diameter, which is probably a captured planetesimal perhaps similar to some KBOs, has a relatively high density of 1.6. However, little is yet known about the densities of KBOs in the few hundred km size range typical of most known KBOs.

Our only direct determination of the masses of KBOs comes from observing the orbits of binary or multiple KBO systems. Radiometric or other diameters for these systems then provide density information. Binary-derived masses have previously been used to constrain densities by assuming an albedo, or vice versa (Noll et al. 2004a,b), suggesting either surprisingly low densities (< 1.0 g cm\(^{-3}\)) or high albedos, but independent determination of albedo and diameter is needed to determine density itself. (47171) 1999 TC36 is the only binary KBO bright enough for radiometric diameter determination using ground-based sub-mm data (Altenhoff et al. 2004) and short-exposure Spitzer GTO observations (Stansberry et al. 2006), providing a preliminary density of 0.55 ÷ 0.8 g cm\(^{-3}\), implying significant porosity even for a pure water ice composition- surprising for such large objects (primary diameter ~330 km, secondary diameter ~140 km).

Only other known sub-1000 km diameter binary KBO is bright enough to be observable in thermal emission by Spitzer with useful S/N: (26308) 1998 SM165, though long exposures are required. In order to determine a radiometric diameter, and thus a density, we observed its 24 and 70 micron thermal emission using Spitzer/MIPS in January 2006, with a total integration time of 7 hours in each band. We also obtained a visible lightcurve at the Lowell Observatory 72” telescope in December 2005, and determined that the primary’s rotational period was 8.40 ± 0.05 hours rather than the previously-published value of 7.96 hours (Romanishin et al. 2001). By obtaining fluxes at both 24 and 70 microns we can obtain a fairly model-independent radiometric diameter: to first order the relative brightness at the two wavelengths defines a color temperature, which combined with the absolute brightness determines the projected area of the body assuming isothermal blackbody emission. Thermal models that account for the temperature distribution across the body allow refinement of the size estimate.

The data appear to be of sufficient S/N to provide a useful radiometric albedo and diameter constraint, and thus a density, for 1998 SM165, and we will report estimates of these quantities at the meeting.

References
Abstract: WSO/UV is an international collaboration led by Russia (Roscosmos) to build an UV (100–310nm) mission with capabilities which are presently, in the near and long term future unavailable to the world-wide astronomical community. The mission consists of a 1.7m telescope able to perform: i) high resolution (R~55,000) spectroscopy by means of two echelle spectrographs covering the 100–310 nm range; ii) long slit (1 × 75 arcsec) low resolution (R~500-5000) spectroscopy; iii) deep UV and diffraction limited optical imaging. WSO/UV will be operated like a ground-based telescope, i.e. capable to perform “real time” operations in an orbit free of visibility constraints (L2).

The topics that can be addressed by WSO/UV concern numerous astrophysical aspects, from planetary science to cosmology. In this paper we give information on the instrumentation on board the WSO/UV mission and highlight the opportunity WSO/UV will offer to Solar System studies.
Abstract title: Irradiation of water, ammonia, and their mixtures
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Abstract: UV Lyman-alpha photons and fast ions are able to fully amorphize the crystalline water ice structure after a dose of few eV per molecule (Leto & Baratta, 2003). This result has been recently confirmed by spectroscopic studies in the visible and near-infrared range; in particular Leto et al. (2005) and Mastrapa & Brown (2006) showed that the 1.65-µm band, whose intensity is a measure of the temperature of crystalline water ice, is destroyed after ion irradiation. Here we show NIR spectra of water ice (T=16-80 K), before and after ion irradiation, and an estimation of the astrophysical timescale for the process.

We also studied pure ammonia, and mixture H2O:NH3=1:1, in the NIR spectral range. We find that, after ion irradiation with 200 keV protons, NH3 is destroyed much faster than H2O, confirming previous results obtained in the MIR spectral range (Strazzulla & Palumbo, 1998). This imposes tight constrains on the amount of ammonia that could be detected on the surface of irradiated TNOs, Centaurs or satellites, and its relation with the presence of crystalline or amorphous water ice.

Abstract title: Laboratory simulations of planetary surfaces space weathering induced by solar wind and cosmic ions

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Abstract: An ongoing research program performed at our laboratory has the aim to investigate the Visible and near-IR (0.3-2.7 micron) reflectance spectra of materials representative of the surfaces of Solar System minor bodies, particularly those of Trans-Neptunian Objects (TNOs). To simulate space weathering by solar and cosmic ions [1-4], spectra of frozen ices (methane, benzene, methanol, etc), terrestrial silicates and carbons were obtained before, during and after ion irradiation. All materials irradiated with different ions (H+, He+, Ar+, Ar++, etc), having different energies (from 30 keV to 400 keV), have shown important spectral changes, usually reddening and darkening. The spectral slopes, at increasing ion fluences, of silicatic materials, namely olivine and pyroxene, have been compared with those of some S-type Near-Earth asteroids. We find that the formation of vacancies by solar wind ion irradiation is a physical mechanism that can redden and darken their surfaces on a time scale of about $10^5$ years, time-scale enough to render the studied process the most efficient to explain the observed variety of colors. The results obtained for carbon-rich frozen ices evidence a strong reddening and darkening of the spectra and the formation of an organic (C-rich) refractory residue. The comparison of spectral colors with those of some Centaurs and TNOs shows that many icy objects in the outer Solar System may have formed an irradiation mantle, produced by cosmic ion irradiation of simple hydrocarbons and/or alcohols, in time scales of about $10^8$ yrs.

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Abstract title: Ion irradiation of TNO surface analogue ice mixtures: the chemistry  
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Abstract: Cosmic ion irradiation is believed to be one of the process driving the evolution of surface materials on TNOs. A fast ion passing through a solid releases its energy in the target by elastic interactions with the target nuclei and by inelastic collisions causing ionisations and excitations. Many molecular bonds are broken along the ion-track and, in a very short time (one picosec or less), the radicals and molecular fragments recombine giving rise to a rearrangement in the chemical structure. As a consequence, in addition to the alteration of the chemical and lattice structure of the target material, new molecular species (not present before irradiation) are formed. Thus, based on simulation experiments carried out in laboratory, some prediction can be made on which molecules could be expected to be present in the surface layers of TNOs. The V-NIR spectra of some Centaurs and TNOs indicate that their surfaces are rich with simple molecules such as H2O, N2, CO2, CH4, and CH3OH. Laboratory experiments have shown that carbonic acid (H2CO3) can be expected on objects with surface rich in H2O:CO2 mixtures (Brucato et al. 1997). Ion irradiation of H2O:N2 mixtures leads to the formation of N2O, NO and NO2. Irradiation of H2O:CH4:N2 mixtures leads to the formation of several species among which carbon dioxide, carbon monoxide, HCN, HNCO, N2O and CN bearing species (Palumbo et al. 2004). Therefore a plethora of not yet identified species are likely to be present because of ion irradiation of TNOs.

In addition to cause the formation of new molecular species, ion irradiation can modify the infrared signature (band profiles) of pre-existing molecular species. This is not surprising since the shape, peak position and the intensity of the IR bands depend on the chemical composition and the structure of the matrix. As an example, ion irradiation of pure methanol ice and methanol mixed with water have shown that the methanol band at 2.34 µm strongly decreases with respect to the one at 2.27 µm (Brunetto et al. 2005). Methanol has been tentatively identified on the Centaur Pholus; Cruikshank et al. (1998) observed the methanol band around 2.27 µm although the band at 2.34 µm was not observed. The fact that the 2.34 µm band has not been observed could be indicative of ion irradiation processes (Brunetto et al. 2005).

References