CONTRIBUTED ABSTRACTS

ABUNDANCES OF GRAVITATIONAL AGGREGATES IN TRANS-NEPTUNIAN POPULATIONS

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Collisional events are a main process in the formation and evolution of planetary systems. In particular, the populations of Trans-Neptunian Objects is largely an outcome of collisional processes in the outer Solar System. Michel et al. (2002, 2003) has modelled that in a collision involving large bodies, fragments produced by the fragmentation process alone can actually interact gravitationally. Therefore, some reaccumulation can occur when relative speeds between fragments are below their mutual escape speeds, and can eventually lead to a distribution of large gravitational aggregates (sometimes called "rubble piles").

One interesting feature of gravitational aggregates (GAs) is that they may respond in a different way than monolithic objects to collisions. In particular they may be less efficient in delivering kinetic energy to ejected fragments.

We have developed a collisional evolution model for the different dynamical populations of TNOs, taking into account their mutual interactions as well as the velocity distributions in every population. We basically start every simulation with an initial distribution of monolithic bodies, and we take into account the evolving populations of GAs. In this way we study the dependence of the abundance of GAs (in every dynamical population) on different initial TNO environments.

On the other hand, this model also allows to test the dependence of the abundances of GAs on poorly known physical parameters, such as the fraction of kinetic energy delivered into fragments (f_{ke}), different scaling laws, potentially different responses to collisions with same energies but different momentum.

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RADAR IMAGES OF BINARY NEAR-EARTH ASTEROID 2006 VV2

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We report Goldstone (8560-MHz, 3.5-cm) and Arecibo (2380-MHz, 13-cm) delay-Doppler radar images of 2006 VV2 that were obtained during March 27-April 3, 2007. The images achieve resolutions as fine as 15 m/pixel, place thousands of pixels on the object, and reveal that this object is a binary system. With a diameter of 1.8 km, the primary is modestly irregular and asymmetric. Its surface has several prominent concavities, possibly including craters, and features along the leading edges that resemble the pronounced ridge seen along the equator of binary asteroid (66391) 1999 KW4 (Ostro et al., 2006, Science 314, 1276). Several small, radar-bright features are evident on the primary and are reminiscent of features seen on (100085) 1992 UY4, which may be blocks similar to those seen on (25143) Itokawa by the Hayabusa spacecraft. The images resolve the secondary in Doppler frequency and range, suggest that it is roughly 500 m in diameter, and place an upper bound on its rotation period of 32 hours. The radar data cover multiple rotations by the primary and the combined radar plus photometric datasets should yield detailed 3-D shape estimates of both components and possibly the system's orbital parameters, mass, and bulk density.

AN ASTEROID SHOWER OVER THE CRETACEOUS PERIOD

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The terrestrial and lunar cratering rate is often assumed to have been nearly constant over the last 3 Gy. Different lines of evidence, however, suggest the impact flux increased by at least a factor of 2 over the last 100-200 My. Our work shows that that this apparent surge was triggered by the catastrophic disruption of the Baptistina parent body, a $\sim$ 170 km diameter carbonaceous chondrite-like asteroid that broke up 160^{+30}_{-20} My ago in the inner main belt region. Approximately 15-20% of Baptistina's multi-kilometer fragments were directly injected or drifted by Yarkovsky thermal forces into the 7:2 mean motion resonance with Jupiter (J7:2), where at their peak $\sim$ 100 My ago, they increased the near-Earth object population by a factor of 3. By combining our numerical results together with meteoritic constraints, we find the Baptistina asteroid shower is the most likely source ($>$ 95% probability) of the Chicxulub impactor that produced the Cretaceous-Tertiary (K/T) mass extinction event 65 My ago.

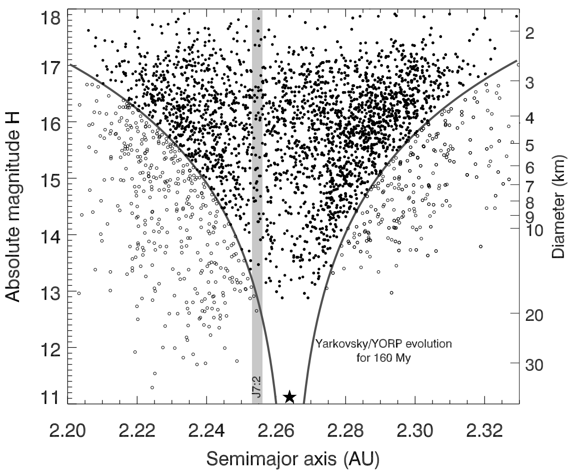

Figure 1: The Baptistina asteroid family (filled circles). The family is noticeably depleted near the J7:2 ($a \approx 2.2545$ AU). The gray lines that bracket the outside of each lobe represent our best estimate of how far the majority of family members spread by Yarkovsky/YORP evolution in $\sim$ 160 My. The open circles are predominantly interlopers from the Flora family.

CATASTROPHIC DISRUPTION ON CORE-MANTLE MIXED ICE-SILICATE TARGETS IN THE LABORATORY

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The population of the Kuiper Belt consists of a collection of icy bodies found outside the orbit of Neptune. While the majority of these objects are relatively small, more and more Pluto-sized bodes are being discovered (such as Eris, Sedna and Quaoar; Brown et al., 2006, Brown et al., 2004) which points to a significant population of this category of bodies existing in the Kuiper belt and the Scattered Disk. The collisional disruption rate of these objects is required to model their size distribution and lifetime as well as their collisional evolution, and this requires a knowledge of Q* (the disruption energy) at these size scales.

The measured density of Pluto (2.05 g cm^{-3}) implies a mixed rock:ice content for these bodies. It is also suspected that Pluto possesses a differentiated structure with a thin layer of ice covering an ice-silicate core (McKinnon et al. 1997). If Pluto is taken as typical, then this composition and structure need to be reflected in any detailed modelling of the collisional evolution of these bodies

As a first step to improving our understanding of the disruption of bodies with such a composition and structure, a range of impact experiments have been carried out at the laboratory scale. The impacts were carried out using a two-stage light gas gun at the University of Kent, firing millimetre sized projectiles of varying densities at velocities ranging between 1 and 7 km s^{-1} (Burchell et al., 1999). The targets were spherical, with diameters on the cm scale. A range of target types was used: pure water ice, mixed sand:ice targets and targets with a core (sand:ice) and mantle (ice) structure. From these impacts the critical energy density Q* for each target type has been found, and is compared with previous impact experiments. This comparison allows us to see whether target composition and structure affects the value of Q* on the laboratory scale.

Further work is still required to extrapolate this data to Plutino size scales, where gravity effects may dominate (i.e. for large bodies Q* will be dominated by the need to disperse the shattered bodies against their self gravity). However, the sensitivity of disruption to target structure and composition in the strength dominated regime has been explored in this paper.

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A SEARCH FOR SPECTRO-DYNAMICAL ASTEROID FAMILIES

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Dynamical asteroid families are normally identified as concentrations of objects in proper orbital element space. These clusters are believed to result from the collisional disruptions of once larger parent bodies. If an asteroid family contains the remnants from such a collision, then the members of that family should be genetically related, and their range of compositions should make cosmochemical, as well as petrological sense. In particular, if a differentiated parent body was disrupted, the resulting family may contain fragments from different lithologic layers within the parent. Recent studies have tested the genetic reality of dynamical asteroid families through analyses based on spectral reflectance colors and taxonomic classifications of family members (eg Bus 1999, MIT PhD thesis, Ivezic et al. 2002, AJ 124:2943, Mothe-Diniz et al. 2005, Icarus 174:54). These studies generally revealed moderate-to-high levels of spectral homogeneity among the members of each family, implying little variation in composition across the interiors of the parent bodies. Given this result, Bus (1999) proposed a method of searching for spectro-dynamical asteroid families that combines both orbital elements and spectral parameters in the cluster analysis. The first application of this method focused on asteroid families with semi-major axes between 2.7 and 2.8 AU, and utilized visible-wavelength spectra for 465 asteroids obtained during the SMASSII survey (Bus and Binzel 2002, Icarus 158:106). From this initial study, a total of 19 spectro-dynamical clusters were identified within this central region of the main belt. In the effort described here, the search for spectro-dynamical families is expanded to cover the entire main belt, utilizing data for 2,074 asteroids taken during three major spectroscopic surveys: the first and second phases of the Small Mainbelt Asteroid Spectroscopic Survey (SMASS, Xu et al. 1995, Icarus 115:1, Bus and Binzel 2002), and the Small Solar System Objects Spectroscopic Survey (S3OS2, Lazzaro et al. 2004, Icarus 172:179). By including spectral parameters derived from these data in the cluster analysis, boundaries of known families can be more accurately determined, close or overlapping families in orbital element space can be separated, interlopers can be identified, and older, more diffuse families that might otherwise be missed can now be recognized. I will discuss the algorithms used in searching for spectro-dynamical families, and will present some of the results obtained thus far.

THERMAL INERTIA OF NEAR-EARTH ASTEROIDS AND IMPLICATIONS FOR THE STRENGTH OF THE YORP EFFECT

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A number of recent works[1-9] have shown that the thermal inertia of the surfaces of small, km-sized near-Earth asteroids (NEAs) is in general between two and three orders of magnitude higher than that of large main belt asteroids[10] with sizes in the range between 200 and 1,000 km. This confirms the idea that large main-belt asteroids, over many hundreds of millions of years, have developed substantial insulating regolith layers, responsible for the low values of their surface thermal inertias, whereas km-sized asteroids, which have collisional lifetimes of some millions years, have less regolith, and consequently a larger surface thermal inertia. It is commonly believed that regolith on asteroids forms as a result of impact processes. The capability of a body to develop a layer or regolith is clearly influenced by its gravity and by the porosity of the material at its surface. In particular, the latter affects the amount, the size distribution, and the velocity of the debris ejected during impacts[1,8]. In this respect, a better knowledge of asteroids thermal inertia and its correlation with other physical parameters such as size, taxonomic type, and density can be used as an important constraint for future modeling of impact processes on asteroids.

The value of the thermal inertia also plays an important role in the YORP effect: it has been shown that while the acceleration of the asteroid rotation rate is largely independent of the thermal inertia, this is not the case for the rate of change of the obliquity, in the sense that the higher the thermal inertia the larger the mean value of the obliquity variation[11].

Several questions still remain open: one of the most important is whether small main belt asteroids (with sizes < 20 km) display thermal inertias as high as NEAs of the same size do. In fact regolith on NEA surfaces can be modified by processes such as close encounters with planets causing tidal disruption that do not affect asteroids in the main belt. Such processes might have been able to alter or strip off the regolith of some NEAs. Thus, while NEAs may be a good proxy for small main-belt asteroids, more observations and modeling work are needed to confirm this point.

TWO NEW BASALTIC OBJECTS IN THE OUTER MAIN BELT

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The existence of basalt on the surface of asteroids provides information about their thermal history that is likely related to their formation and collisional evolution. Basaltic materials on the surface of an asteroid are indicators of past partial melting, a phenomenon that occurs due to the complicated interplay of heating and cooling processes within the interior of rocky bodies. Until recently, most of the known basaltic asteroids, taxonomically classified as V-type, were members of the Vesta dynamical family. Currently, several V-type asteroids are know to reside outside the Vesta family (e.g. [3][8]), and several NEAs with basaltic mineralogical surface composition have been recognized (e.g. [5] [1][6]). The asteroid (1459) Magnya, a basaltic object in the outer asteroid belt [10], is sufficiently distant from the Vesta family so that its probability of origin from this family is very low [11]. [12] presented the possibility of searching yet unknown V-type asteroids using photometric data from the Sloan Digital Sky Survey (SDSS). A sub-product of this survey is the Moving Objects Catalog (MOC), which in its third release provides five band photometry for 43424 asteroids [7][9]. [12] introduced a systematic method to identify possible candidate V-type asteroids from the SDSS-MOC, applying the Principal Components Analysis to the data. They found 263 V-type candidates that are not members of the Vesta dynamical family. The most interesting result is the presence of 8 V-type candidates in the middle/outer asteroid belt, i.e. with $a > 2.5$ AU: (7472), (10537), (21238), (40521), (44496), (55613), (66905) and (105041). These asteroids are quite isolated in proper elements space and do not belong to any of the major dynamical families. They are not close in proper elements space to (1459) Magnya either. In a recent study, [2] analyzed the spectra of (21238) in the near infrared (NIR) and confirmed its basaltic nature. In this work we present low resolution spectra in the visible range of (7472) Kumakiri and (10537) 1991 RY16 have been obtained by us on November 14th, 2006, using the Calar Alto Faint Object Spectrograph (CAFOS) at the 2.2m telescope in Calar Alto Observatory, Spain. The reflectance spectra of the two bodies seem to correspond to that of a V-type asteroid. However, the presence of a shallow absorption band around 0.6 microns, which has never been observed before in other V-type spectra, precludes these objects from being classified by any existing taxonomic system [4]. It is worth noting that the observed band is real and its presence in the spectrum of (10537) has been confirmed independently by other observers (Moskovitz et al., 2007). Therefore, we do not know whether we have discovered two basaltic asteroids with a very particular and previously unseen mineralogical composition or two objects of non basaltic nature that have to be included in a totally new taxonomic class. To unambiguously determine whether our targets have basaltic surfaces, we will observe in the near-infrared range.

A NEWLY IDENTIFIED SOLAR SYSTEM DUST BAND

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The relative proportions of asteroidal and cometary material in the zodiacal cloud is still an ongoing debate. The zodiacal cloud consists of a broad, low-frequency background, with a superimposed high frequency, fine-structure component known as the dust bands. The dust bands have been confidently linked to specific, young, asteroid family disruptions in the main belt. These disruptions represent recent injections of dust into the zodiacal cloud and thus hold the key to determining at least a minimum value of the asteroidal contribution to the cloud. There are currently known to be 3 dust band pairs, one at approximately 10 degrees corresponding to the Veritas family and 2 central band pairs near the ecliptic, one of which corresponds to the Karin cluster of the Koronis family. Through careful co-adding of almost all the pole-to-pole intensity scans in the mid infrared wavebands of the IRAS data set, a new solar system dust band has been found at approximately 17 degrees inclination. We present preliminary modeling of the new band, including its cross-sectional area, as well as potential candidates for the source of these catastrophic collisional debris.

HYPERVELOCITY IMPACT EXPERIMENTS TO STUDY CRATERIZATION AND CATASTROPHIC FRAGMENTATION OF MINOR BODIES IN THE SOLAR SYSTEM

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A deeper understanding of impact fragmentation and of collisional breakup processes is needed to investigate the evolution of the minor bodies of the Solar System and also for developing more complete and accurate theoretical models. We present an experimental study of impact cratering and fragmentation processes onto low density materials by means of high velocity impact experiments using a two-stage light-gas gun, the impact facility of CISAS "G. Colombo" of the University of Padova (http://cisas.unipd.it/lgg/lgg.html). The goal of our experiments is to obtain a better comprehension of the impact processes on different materials in order to analyse the evolution of planetary surfaces and the collisional evolution of the minor bodies of the Solar System and to support the space missions to asteroids and comets for data interpretation, mission design and risk mitigation. Porosity is an important physical characteristic of the minor bodies, affecting their behaviour during cratering and greatly lengthening the collisional lifetimes of asteroids. Therefore we focus on the study of impact processes on porous targets both by experimental and theoretical approach in order to complement and extend the available data to ranges of velocity and physical conditions not yet explored. Impact test campaigns have been performed on samples of different material and porosity in order to study the craterization up to catastrophic disruption. Furthermore, numerical simulations have been performed by using Smooth Particle hydrodynamics (SPH) technique in order to validate the experimental data. Results of the study of impact processes on porous targets will be presented also in comparison with other experimental data.

DISRUPTION EXPERIMENTS ON HYDROUS METEORITES

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The outer half of the main-belt is dominated by asteroids that are classified as C-, P-, or D-type, based on their reflection spectra. These low-albedo asteroids are believed to be the parent bodies of the carbonaceous chondrite meteorites. A significant fraction of the carbonaceous chondrite meteorites are hydrated, and some of the C-, P-, and D-type asteroids show evidence for hydration in their reflection spectra. Thus, a significant fraction of the targets for cratering and collisional disruption in the outer half of the main-belt are likely to be hydrated bodies. Nonetheless, most disruption experiments on natural rock targets have concentrated on anhydrous rocks, such as basalts. To begin to recitify this situation, we have undertaken a series of impact experiments on hydrous meteorites – the Murchison CM2 chondrite and three other CM2s collected in the Antarctic. We disrupted a 30.09 gram elongated whole stone of the Murchison CM2 meteorite using a 1/8th inch diameter Al-sphere fired at 4.45 km/sec using the NASA Ames Vertical Gun Range (AVGR). Six passive detectors, each containing two 7 micron and two 13 micron thick Al-foils, a single 51 micron thick Al-foil, and two aerogel capture cells were deployed in the AVGR chamber to record/capture debris from the disruption. We measured the mass frequency disruption of the fragments produced by the Murchison disruption by combining the data from the foil penetrations with the data from the fragments recovered from the floor of the AVGR. This cumulative mass-frequency distribution of fragments from the Murchison shot is reasonably well fit by a single power-law over the range from 10-6 grams to the largest fragment, however it is almost flat for masses smaller than 10-6 grams. Compared to Allende and the ordinary chondrites we disrupted previously, this Murchison disruption produced an overabundance of dust ¿10-5 grams, but an underabundance of dust ¡10-6 grams. Preliminary results suggest that Murchison and the three Antarctic CM2s have similar "strength," i.e., produce a similar ratio of largest fragment to target mass for a given specific impact energy, to that of the anhydrous meteorites we previously disrupted.

CRUSH CURVE MESSUREMENTS OF POROUS MATERIALS USED FOR LABORATORY IMPACT EXPERIMENTS

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@As the impact process is common in the solar system, it is important to understand the impact process of small bodies in order to study the origin and evolution of these bodies and the solar system. The scale of the impact process in the solar system is far larger than we can address in the laboratory directly. Therefore, numerical simulations offer an effective way to study the impact process of small bodies. However, numerical simulations require knowledge of the physical properties of the target material, and should reproduce the results of laboratory experiments. Therefore, laboratory studies of the physical properties of the target materials, and destruction experiments, are important for numerical simulations.

@In numerical simulations of the collisional disruption of asteroids, a fracture model, the Grady-Kipp model, has been used (Benz and Asphaug, 1994). The Grady-Kipp model represents cracks statistically using the nucleation and propagation of flows determined from an initial distribution. Increasing numbers of small porous bodies have been found in the solar system (Britt et al., 2002). Since the pores in a porous material stop crack growth, it is not clear how applicable the Grady-Kipp model is to the simulation of porous materials.

@In this study, we measured the crush curves of samples, i.e., stress-strain curves during static loading, and compared them with the static compressive strength of the samples. The porosity of sintered glass beads, gypsum, and pumice specimens is about 40, 50, and 72%, respectively. These samples were used as targets for laboratory impact experiments. The shapes of the crush curves differ from one other, probably due to the sample porosity and microscopic structure. We will discuss further how porous samples are destroyed.

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COLLISIONAL DAMAGE OF ROCKY ASTEROIDS

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By virtue of its name, much of the discussion at the CD workshops has concentrated on the nature of catastrophic collisions. However, impacts at energies below the catastrophic threshold also have an important effect on an asteroids collisional evolution. For example, repeated subcatastrophic collisions affect an asteroids internal structure and strength. Each impact introduces damage in regions near the impact point and perhaps in distant regions due to tensile reflections of the shock from free surfaces. Experiments have shown that repeated low-energy impacts are about as effective in disrupting a target as a single collision of equal total energy. Calculated collisional lifetimes based on a single catastrophic event are therefore too long. Impact damage may have an even larger effect on the lifetimes of rapidly rotating asteroids. A rocky, strength dominated asteroid remains coherent only if its rotation rate is below the stability limit, where the tensile stresses due to rotation are smaller than its global tensile strength. Suppose that an asteroid, spinning well below its stability limit, experiences an impact that would be subcatastrophic to a similar, but nonrotating body. If the impact reduces the strength of the asteroid sufficiently, the spin state would then be above the stability limit and the asteroid would be disrupted. Consequently, it is important to understand not only how the mechanical properties of an asteroid affect its response to collisions, but also how collisions affect its mechanical properties. This talk will summarize the results of experiments that explore the effects of subcatastrophic events on the collisional history of rocky asteroids.

OBSERVATIONS OF THE FRAGMENTED COMET 73P/SCHWASSMANN-WACHMANN 3

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The fragmented Comet 73P/Schwassmann-Wachmann 3 was observed using both the Arecibo (12.6 cm) and Goldstone (3.5 cm) planetary radar systems on 10 nights in May 2006. Although the disruption of a comet nucleus is not an impact process, it can lend valuable insights into the internal structure of these small icy bodies. We obtained radar spectra and images of both the comae and nuclei of fragments B and C. 73P is only the second comet whose nuclei have been imaged with radar and the first at sub-50-m resolution. We also obtained the first radar images of a cometary coma, which reveal a population of 2-cm particles and larger. The velocity distribution of these particles are size-dependent: smaller particles are moving at higher velocities. Spectral line observations of the OH in the coma for fragments B and C were also obtained, both at Arecibo and the 100m Green Bank Telescope. From the line width, we derive an average outflow velocity of 0.73 +/- 0.04 km/s of water from the nucleus. The outflow velocity from fragments B and C are indistinguishable between 17 April and 22 May 2006. We obtained images of the nuclei at resolutions as fine as 15 m per pixel. The delay-Doppler images of fragment C show it to be a rounded, somewhat irregular object approximately 2 km in diameter, with a firm lower limit of 1 km. There are clear indications of features, similar to craters and other topographical features seen in spacecraft images of other cometary nuclei. The images of fragment B, are unusual, but indicate a diamater no smaller than 400m. Since the gas production rates of fragments B and C are similar, the active area of fragment B must be much larger. This is not surprising since it is a fresher fragment. Both fragments are irregular in shape and have rotation periods longer than 10 hours.

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DETECTING MAIN BELT ASTEROID COLLISIONS IN REAL-TIME WITH PAN-STARRS

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The catastrophic disruption rate of main belt asteroids larger than a few tens of meters in diameter is expected to be on the order of one per day while an asteroid larger than 100 meters in diameter is destroyed roughly every year (bottke, 2005). These disruptions will produce expanding dust clouds of debris that should be detectable from the Earth as long as their optical depth is > 1 and they reach a diameter equivalent to the size of an asteroid detectable with a telescope system. Thus, the next generation of large aperture synoptic surveys may be capable of detecting the aftermath of these collisions. The possibility of identifying the collision products offers an opportunity for confirming the size-distribution and collision rate at asteroid sizes too small to be observed directly and, with rapid photometric or spectrographic follow-up, the tantalizing option of physical characterization of their bulk properties.

The Pan-STARRS collaboration at the University of Hawaii's Institute for Astronomy is nearing completion of a prototype 1.8m diameter wide-field surveying telescope (PS1) on Haleakala, Maui. This telescope, and the eventual full Pan-STARRS system consisting of 4 similar telescopes working in tandem (PS4), will be capable of imaging the entire night sky in three or four nights. The PS1 system will be capable of detecting 1 km diameter asteroids, or the 1 km diameter dust cloud resulting from the catastrophic collision of smaller asteroids, out to a heliocentric distance of about 2.7 AU while the PS4 system will be complete through the main belt to this size.

I will discuss the use of the Pan-STARRS telescope systems for identifying real-time main belt asteroid collisions, the signatures of the collisions in the Pan-STARRS data, and the requirements for rapid follow-up of new discoveries.

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SIMULATIONS OF THE LCROSS IMPACT USING SMOOTH PARTICLE HYDRODYNAMICS (SPH)

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Introduction We present results of hydrocode calculations of the impact of the Lunar CRater Observation and Sensing Satellite (LCROSS) spacecraft on the moon. This NASA mission is planed for late 2008. The spacecraft with a weight of 2000kg will impact the moon with a velocity of about 2.5 km/s. Using our Smooth Particle Hydrodynamic (SPH) impact code, we investigate the crater formation, crater morphology, velocity distribution of ejecta etc. for different target material (regolith) properties including strength and porosity.

Numerical method Our numerical tool is based on the Smooth Particle Hydrodynamic (SPH) method. In order to simulate solids, standard SPH was extended to include a strength and a fracture model (Benz and Asphaug, 1994). Therefore, our SPH impact code can be used to model impacts and collisions involving solid bodies in the strength- and gravity-dominated regime. This method was already successfully tested at different scales.

Recently, our SPH impact code was extended to include a porosity model. The model is based on the so called P-α model (Herrman 1969) which was adapted for implementation in our SPH code (Jutzi 2004). We are now capable of performing SPH simulations including fracture and porosity.

Impact simulations Using our 3D SPH impact code, we perform several simulations of the LCROSS impact, considering different properties of the target material. For example, we compare simulations of the LCROSS impact in porous and nonporous targets and we also study the influence of the surface topography. For these different types of targets, we investigate the velocity distribution of ejecta, the corresponding maximum height and also the initial depth of the ejected material. We also make estimations of the crater diameter and crater depth. Different models of the impactor are used for this study.

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EVOLUTION OF DUST PARTICLES EJECTED BY CATASTROPHIC ASTEROIDAL DISRUPTIONS

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The contribution of asteroidal dust to the zodiacal cloud has previously been discussed in terms of a collisional cascade process, whereby dust is produced by the grinding down of large objects. However, there is now evidence that debris disks, such as the zodiacal cloud, are refreshed stochastically by the injection of dust produced by the catastrophic collisional breakup of a large planetesimal. Asteroid families provide dramatic proof of the occurrence of such collisions in the solar system. There are now known to be at least two examples of asteroids, tens to hundreds of kilometers in diameter, that have been catastrophically disrupted by an impact within the last ten million years. These collisional events resulted in the creation of the Veritas family and the Karin cluster. Enormous quantities of dust are injected into the zodiacal cloud following such family-forming impact events and the remnants of the collisional debris produced by these disruptions can still be observed today in the form of dust bands. Following its production, this material evolves both dynamically and collisionally, with the result that a wave of dust particles is transported from its source region in the asteroid belt into the inner solar system

Evidence shows that many asteroids are not coherent, solid bodies but are instead highly fractured, highly porous, and only loosely bound by gravity. Dust may be generated by impact processes in the regoliths of such "rubble piles" and so the contribution of asteroidal dust to the zodiacal cloud may be determined by a quite different mechanism to the collisional cascade process, with only a few rubble piles providing the majority of asteroidal dust in the solar system at any particular epoch. These asteroids appear to maintain their internal porosity despite the accumulation of fine-grained deposits on their surfaces. It has been found that the effect of friction on this material dominates over an asteroid's weak gravitational field. This effectively traps any accreted or micrometeorite-produced dust on asteroid surfaces, making it readily available for ejection into the zodiacal cloud.

We will present preliminary results from numerical simulations of the dynamical evolution of dust particles released from the regolith layers of such catastrophically disrupted rubble-pile asteroids. Estimates of the cross-sectional area of material produced and its size-frequency distribution will be constrained by comparison with models of the dust bands associated with the Veritas family and the Karin cluster.

ASTEROID FAMILIES: STATISTICAL IDENTIFICATION OF NEW FAMILIES AND DETERMINATION OF SIZE DISTRIBUTIONS OF FAMILIES' MEMBERS

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Statistical method of identification of the asteroid families is proposed. It is based on searching for the local heterogeneities of the asteroid distribution density in the space of the proper elements *a, e, i,* appropriately scaled in the units of length. The procedure are performed in the spherical area $\Omega[AU^3]$ centered in several asteroids. The method was tested on the well recognized families, and next it was applied for searching of the new ones. In Fig. 2 there are given some examples of space distribution of asteroids in the families (Fig. 2, upper row) as well as in the vicinities of the asteroids non-having the families (Fig. 2, lower row). For the families the sharp pick in the vicinity of main family member is clearly visible. Large data set (130037 numbered asteroids) is used. So, the population of identified families is considerably more numerous than it is given by the literature. For the first 200 numbered asteroids we have identified 12 previously known families as well as we discovered 10 new families. Of these the most populated are the families 73 Klytia and 46 Hestia with 1300 and 420 members, respectively. For all considered families the size distributions in the power-law form were determined. The diameters of the family members are $D = 1329 \cdot 10^{-H/5} p^{-1/2}$ [km]. Here H is the absolute magnitude of the asteroid and albedo p of all asteroids is assumed to be the same and equal to 0.15. The size distributions are aimed to be interpreted on the basis of modelling of impact disruption processes.

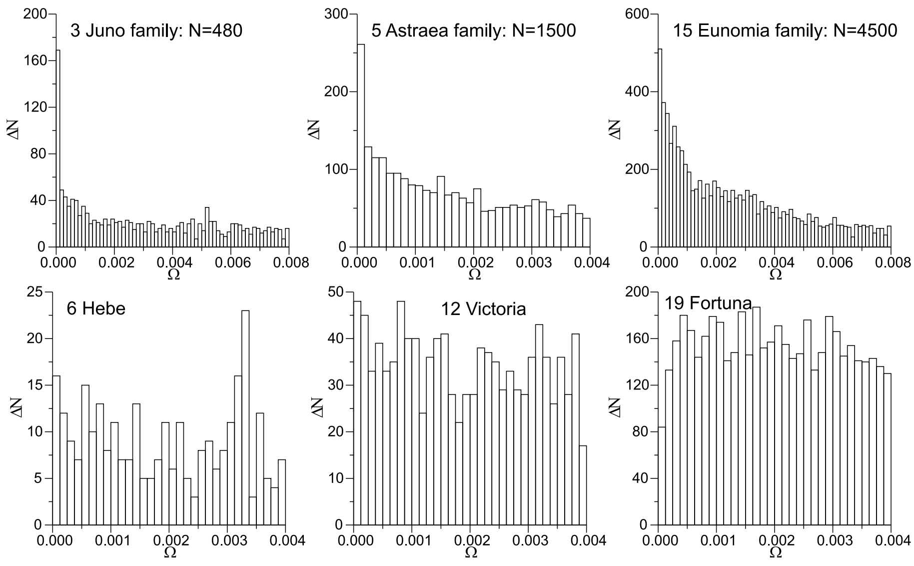

Figure 2: Examples of distribution of asteroids ΔN [asteroids/bin] versus volume $\Omega[AU^3]$ in the proper elements space.

APPROACHING THE INTERNAL STRUCTURE OF THE NUCLEI OF COMETS

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It has been understood, since comet Halley flybys, that the density of cometary nuclei is very low. More recently, observations of the solar light scattered by dust ejected from nuclei, together with elaborate simulations, have suggested that a fair amount of the refractory component consists in fluffy aggregates built up from sub-micronic grains [1, 2]. Deep Impact and Stardust have recently confirmed these estimations. Amongst other unique results, these missions have respectively provided a fair estimation of the density of the nucleus of comet Tempel 1, 350 250 kg m-3 [3], and given evidence for the existence of both dense grains and aggregates with low bulk density within the coma of comet Wild 2 [4]. While it is now recognized that nuclei are most fragile and that fragmentation events reveal changes in the dust properties [5], the internal structure of the nuclei is still unknown. In less than 8 years, the CONSERT experiment on board the Rosetta probe should investigate the deep interior of comet Churyumov-Gerasimenko, from measurements of the propagation delay of long wavelength radio waves [6]. A detailed analysis of the waves passing through the nucleus will put constraints on the materials and on the heterogeneities within the nucleus. Meanwhile, further studies of the morphology of cometary dust and of the thermal structure of cometary nuclei should allow us to provide more constraints for the catastrophic disruption of dormant or defunct nuclei.

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MUTUAL ORBIT, BULK DENSITY AND FORMATION SCENARIO OF VISUALISED MULTIPLE ASTEROIDS

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The advent of high angular resolution imaging provided by instruments such as ground-based telescopes equipped with adaptive optics (AO) systems, and also by the Hubble Space Telescope, permitted the discovery of several visualized mutiple asteroids on the last decade. At the time of writing, more than thirty systems have been imaged, including two triple asteroid systems: 45 Eugenia and 87 Sylvia. Despite recent simulations involving catastrophic collisions, fission via the YORP effect, and split due to tidal effect with a major planet among others, the formation of most of these multiple asteroid systems is not yet understood. Insights into these binary systems, such as the orbital parameters of the satellite, the size and shape of the components of the system, the physical and chemical properties of their surface, their bulk density and distribution of materials in their interior could provide a better understanding of how these multiple asteroidal systems formed. Over the past few years, our group has focused its attention on binaries located in the main-belt which have been discovered visually. We initiated an intensive campaign of observations from 2003 through 2006 combining the adaptive optics high-resolution capabilities of various 8m-class telescopes (UT4 of the Very Large Telescope, W.M. Keck-II and Gemini-North) equipped with Adaptive Optics (AO) systems that allow us to resolve the binary system. This project aims at studying the binary asteroid characteristics using high angular capabilities provided by large aperture telescopes with AO systems. We have separately published a complete analysis of the orbit, size and shape of 90 Antiope, a similarly sized doublet asteroidal systems (Descamps et al., Icarus, 2007). We performed the same analysis for binary asteroids with small satellite publishing a complete analysis of 12 binary systems (Marchis et al., Nature, 2005; Icarus 2007ab). Our work revealed a large diversity in their mutual orbits suggesting a different origin and evolution. Their bulk density is quite variable depending of their taxonomic classes and, in most of the case they have a significant macro-porosity (>30%) suggesting a rubble-pile interior.

This talk will give us the opportunity to present a synthesis of these multiple asteroid system properties, including additional studies in progress (lightcurve of mutual events in visible) and future ideas (comparative spectroscopy) which will help to get insights on the formation process of these systems.

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THE THOUSAND ASTEROID LIGHT CURVE SURVEY. PRELIMINARY RESULTS

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Current surveys of Main Belt asteroid rotation tend to be biased towards the largest, brightest, and closest targets. The Thousand Asteroid Light Curve Survey (TALCS) has been designed to find the rotation periods of nearly 1000 Main Belt asteroids in a magnitude-limited survey of 12 square degrees of the ecliptic. Our survey is complete through the Main Belt down to diameters of 1 km, and our observing cadence over the two-week baseline ensures sensitivity to both slow (Period$\sim$ 1 day) and fast (Period$<$ 2 hours) rotators. Color information of the targets allows us to make coarse spectral type designations and thus estimate albedo to determine the size of the objects.

In this talk we present preliminary results from the orbital and light-curve analysis of our targets, and discuss their implications for our understanding of the distribution of asteroid rotation periods. We also present the future direction of this project, as well as new supporting projects and instruments.

CATASTROPHIC DISRUPTION OF ASTEROIDS: FIRST SIMULATIONS WITH EXPLICIT FORMATION OF SPINNING AGGREGATES BY GRAVITATIONAL REACCUMULATION

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We have recently made a major improvement in the simulations of asteroid disruption by computing explicitly the formation of aggregates during the gravitational reaccumulation of small fragments, allowing us to obtain information on their spin, the number of boulders composing them or lying on their surface, and their shape. We will present the first and preliminary results of this process taking as examples some asteroid families that we reproduced successfully with our previous simulations.

In the last six years, we have simulated successfully the formation of asteroid families using a 3-D Smoothed Particle Hydrodynamics (SPH) code to compute the fragmentation phase following the impact of a projectile on the parent body, and the parallel N-body code `pkdgrav` to compute the mutual interactions of the resulting fragments, including gravitational reaccumulation (Michel et al. 2001, 2002, 2003, 2004a,b). We found that when a km-size asteroid is disrupted by a collision, it can generate several hundreds of thousands of fragments whose masses are still large enough to be attracted by each other during their ejection. As a consequence, many reaccumulations can take place, so that at the end of the process most of the large fragments correspond to gravitational aggregates formed by reaccumulation of smaller ones. Moreover, this process leads to the formation of satellites (at least temporary ones) around the largest and other big remnants (e.g. Michel et al. 2001, Durda et al. 2004).

However, the main limitation of these previous simulations is that when fragments reaccumulate, they simply merge into a single sphere whose mass is the sum of the masses of these fragments. Thus, no information is provided on the actual shape of the aggregates, their spin, and on the quantity of small boulders composing them or lying on their surface. For the first time, we have simulated the disruption of a family parent body by computing explicitly the formation of aggregates along with the above-mentioned properties. We will present these first simulations and their possible implications for the properties of asteroids generated by a disruption. Such information can for instance be compared with data provided by the Japanese space mission Hayabusa of the asteroid Itokawa, a body now understood to be a fragment of a larger parent body.

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NEAR-EARTH ASTEROID 1999 RQ36.

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Near-Earth asteroid 101955 (1999 RQ36) made a close approach to Earth in 1999 and 2005, and was well observed optically and with the Arecibo and Goldstone planetary radar systems. The Arecibo radar observations in 2005 were designed to measure its oblateness, and thus have unusually good aspect coverage, allowing for a good pole determination. Radar images at 19- and 15-m resolution in 1999 and 7.5-m resolution in 2005 show that RQ36 is well approximated as a triaxial ellipsoid about 700m in diameter with axis ratios 1:1.03:1.06, and shows evidence of small impact craters. There is no evidence in the radar images for a satellite larger than 5m, which would have been detected at a SNR of 30 under pessimistic assumptions about albedo and spin rate. The nearly spheroidal shape suggests that it is a strengthless rubble pile, and may have formed by mechanisms similar to near-Earth binary systems, and may even have been in a binary system in its past. Its spin rate of 4.288 hours [Hergenrother pers. comm. 2007] (the 2.1 hour harmonic is ruled out by the radar data) suggests that it is not currently being spun up by tidal or radiation forces.

1999 RQ36 may be one of the older near-Earth spheroidal asteroids, in contrast with 2006 VV2, which is likely a very young one (see presentation by Benner et al.). Older in this context means time since the most recent spinup event.

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INTERPRETING ITOKAWA'S CRATERING RECORD

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The ∼500 meter long near-Earth asteroid (NEA) Itokawa, recently visited by the Hayabusa spacecraft [see 1], has a cratering record that is significantly under-saturated for craters below ∼100 m in diameter, with meter-scale craters almost nonexistent. The cratering record in this size range is similar to that on Eros, where the depletion of small craters was shown to be consistent with erasure by seismic shaking [2,3]. Using the model of [4], which tracks crater production and erasure, and including a parameterized version of seismic shaking erasure from [2,3] which has been scaled to account for Itokawa being significantly smaller than Eros, we are able to reasonably reproduce Itokawa's cratering record. Even though Itokawa is an NEA, the majority of its craters would have been formed by main-belt impactors. We have tested the best-fit main-belt populations of [5] and [6,7], and find that [6,7] provides the best fit to Itokawa's crater size distribution. That impacting population is also found to be consistent with the cratering records on Gaspra, Ida and Eros. There is still an over-depletion of craters smaller than ∼10 m in diameter on Itokawa, beyond that which is easily explained by equilibrium seismic shaking erasure in our model. Possible explanations that we are exploring include stochastic effects such as a well-timed large impact, or a change in the physics of seismic shaking for very small asteroids.

The most significant uncertainty in this type of modeling is the scaling law used to convert impactor diameter into crater diameter. Using a hydrocode-based scaling law [8], we find that Itokawa's cratering record can be matched after ∼100 Myr of exposure, whereas using a scaling law based on explosion cratering in rock [9], we find that it takes ∼1000 Myr. Uncertainties in the scaling law, therefore, translate to substantial uncertainties in the estimate of Itokawa's age.

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EXPERIMENTAL STUDY ON COLLISIONAL DISRUPTION OF CORE-MANTLE BODIES

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In the accretion process of planetesimals, there could be a lot of bodies with heterogeneous internal structures by pressure sintering, melting and gravity differentiation. They might have a core-mantle structure such as silicate core-porous silicate mantle or metal core-rock mantle. Therefore, we should consider a collisional phenomenon not only of a homogenous body but also of a core-mantle body to study the planetary accretion process. However, we do not have few experimental data on the collisional disruption of a core-mantle body. So, we should investigate the collisional strength and the fragment velocity of core-mantle targets and clarify the differences of these physical processes between homogenous targets and core-mantle targets.

We used a two-stage light gas gun set in Nagoya University and studied the strengths and the fragment velocities for various core-mantle targets. The impact velocities (V_{i}) ranged from 1.5 to 4.6 km/s. The gypsum mantle-glass core targets were prepared for the spherical targets. The glass core was surrounded by the gypsum mantle. We changed the mantle thickness ($t_{\mathrm{m}}/d_{\mathrm{p}}$) and a ratio of the glass core mass to the total target mass (CMR) from 0 to 1. The density of glass and gypsum was 2.5 g/cm^3 and 1 g/cm^3, respectively. The collisional disruption of the core-mantle target was directly observed by high speed photography.

We investigated the relationships between the largest fragment mass and the energy density to determine the impact strength of targets. The core-mantle data having various $t_{\mathrm{m}}/d_{\mathrm{p}}$ and CMR spread between the basalt and gypsum data reported by previous studies. Therefore, we speculated that the behavior of core-mantle targets in collisional disruptions strongly depends on the key parameters, $t_{\mathrm{m}}/d_{\mathrm{p}}$ and CMR.

We compared the antipodal velocities (V_{ant}) normalized by impact velocities among core-mantle targets. As increasing the CMR and decreasing the $t_{\mathrm{m}}/d_{\mathrm{p}}$ at the same energy density, the $V_{\mathrm{ant}}/V_{\mathrm{i}}$ drastically increased. The shock wave going through the gypsum mantle attenuated very much because of the high porosity of the gypsum mantle. So, we obtain the larger $V_{\mathrm{ant}}/V_{\mathrm{i}}$ for the smaller $t_{\mathrm{m}}/d_{\mathrm{p}}$.

We suggest that the physical characteristics of core-mantle targets in collisional disruption depend on the decay rate of shock pressure, the $t_{\mathrm{m}}/d_{\mathrm{p}}$, and the kinetic energy of the projectile partitioned into the glass core.

COLLISIONAL DE–WEATHERING OF ASTEROIDS?

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In a recent paper (Lazzarin et al., 2006) it has been shown that the concept of space weathering, i.e. the evolution of spectroscopic surface properties with time, due to the exposure to external effects, can be extended from the S–complex asteroids to almost all asteroids. In general, the spectral slope changes with the exposure and, as a general rule, the weathering causes reddening, even if the effect is more pronounced for S–type objects, less for the others.

However, other effects are present. This consideration follows from a few evidences:

- The timescale for reddening, as far as we estimate it from laboratory experiments, is shorter than the typical asteroidal ages: thus for most bodies the weathering should be essentially saturated, thus masking the slope–exposure relation, which we find.
- It can be shown that other effects, for instance those connected to close encounters with planets, interact with the usual weathering; the resulting scenario is thus more complex (Paolicchi et al., 2007).
- The analysis of C–complex Near Earth Asteroids shows a different behaviour, both a reversed slope–exposure relation and a by far rarer –compared to Main Belt– presence of aqueous features in the observed spectra; some anomalies involve also the C–complex asteroid families. These properties are yet unexplained, but some suggestions have been presented (Paolicchi et al., 2006).

In general, we will probably have to refine the weathering models to take into accounts a few additional effects, such as heating, which can be due either to the proximity of the Sun (at least for NEAs) or to collisions, and surface alterations due to non–catastrophic collisions (jolting, regolith mixing). We suggest, for the moment at a semi–qualitative level, that the role of collisions should be critical for several features of the spectroscopic evolution: slowing down of the reddening asteroidal timescales and, maybe, also other more selective effects due to heating. In general, we state that collisions should have a de–weathering effect.

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POSSIBLE COLLISIONS OF TNOS WITH SMALL BODIES ON HIGH ECCENTRICITY ORBITS

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We present 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.

Analytical theories about the existence of periodical solutions in the outer variant of the averaged restricted three-body problem (the Sun–Jupiter–asteroid) established the existence of the periodic solutions corresponding to Keplerian osculating orbits in which the eccentricity, inclination and semi-major axis have only periodical perturbations. The node possesses by the secular motion. Therefore, only additional forces can change orbits of the Kuiper-belt objects such that the bodies can migrate to the inner or outer part of the solar system.

One of the possible nongravitational forces that can change a near-circular orbit of some Kuiper object to an elliptical one is the collision with a comet on the high eccentricity orbit. The orbital velocity of a comet from the Kreutz group with a near-parabolic orbit in the region of the Kuiper belt (heliocentric distance 30–50 AU) is 7.7–5.9 $\mathrm{km\,s^{-1}}$. 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 $\mathrm{km\,s^{-1}}$. Depending on the change of the orbital velocity vector, the object will migrate to inner or outer part of the solar system.

SHAPES AND MULTIPLICITIES OF VESTA FAMILY ASTEROIDS: IMPLICATIONS FOR THEIR COLLISIONAL ORIGIN

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A photometric survey of the Vesta family of asteroids was initiated in order to better understand the outcomes of large-scale collisions in the solar system. This family was originally chosen because of its spectrally distinct crustal composition (basaltic) which permits any fragments excavated from it to be easily traceable. Further, the large impact basin on its southern hemisphere is likely to be the source region for the Vesta 'chips', making the Vesta family an ideal subject for the study of large scale cratering impacts. Recently, however, it has been speculated that several collisional events may have contributed to what is currently identified as the Vesta asteroid family, so additional complexities may have to be factored into the evaluation of the collected data.

Since our primary objective is to determine the shape characteristics of the fragments from an impact event, we chose to focus on a small number of targets for which we could obtain detailed photometry during multiple apparitions. Most of the objects observed have displayed the usual doubly periodic lightcurves associated with tri-axial ellipsoids. However, a few have revealed more unusual features. In particular, the lightcurves of 3782 Celle (Ryan et al. 2004a) and 3703 Volkonskaya (Ryan et al. 2004b) are indicative of asynchronous binary systems. In addition, other targets within this survey have revealed unusual lightcurve features that have the appearance of anomalous attenuations, but with periodicities that appear to be synchronous with the primary's rotation.

In the present work, we provide a summary of the latest results of this survey. In particular, we present models of the 3782 Celle and 3703 Volkonskaya binary systems based on anomalous attenuation events observed at differing observing geometries of multiple apparitions, and comment on the implications for understanding satellite formation in subcatastrophic collisions.

This work is supported by the NASA Planetary Astronomy Program and the generous observing time made available by the Vatican Observatory Research Group and NOAO.

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SUBLIMATION TEMPERATURES OF ICES RELATED WITH CATASTROPHIC EVENTS

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Objects as those called TNOs (Trans Neptunian Objects) have ices as important constituents. Molecules as CH_4 or H_2O have been identified (see Barucci et al, 2006) and others as CO_2 (Satorre et al, 2006) have been suggested.

Catastrophic events can produce variations in temperature, causing volatile molecules sublime depending on the temperature that finally it is reached and the mixture of ices present in/on the object.

The ejection of sublimated molecules from the surface could dynamically be important. If the sublimated molecules are inside a fragment, the increase in pressure produced by the sublimation of volatile molecules can produce cracks and ejections or explosions into the fragments, producing additional breakage than that produced directly from the impact (see Holsapple & Housen,2007).

Our contribution will present some physical characteristics (measured in our laboratory) of ices present in objects of the Solar System.

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MINIMUM ENERGY CATASTROPHIC DISRUPTIONS

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Dramatic alteration of an asteroid's morphology need not involve high energy impacts between bodies. Simple sunlight shining on an asteroid can, through the YORP effect, cause it to undergo dramatic reconfigurations, fission into a binary asteroid or, in some cases, even undergo a catastrophic disruption with the asteroid losing up to 20% of its initial mass. The YORP effect has recently been detected and verified [2,3,6], and thus is relevant to study for its effect on asteroid morphology.

In [4], the effect of YORP torques on the asteroid Itokawa is examined in detail. We find that the body is currently undergoing a deceleration in its rotation rate, implying that it was spinning faster in the past. Extrapolating back on the order of 200,000 years we find that Itokawa should have been spinning fast enough for the distinctive "head" and "body" portions of the asteroid to be in orbit about each other. A study of the orbit that would ensue shows that the system would have been highly unstable, but unable to escape. The two portions would most likely have reimpacted, potentially supplying the seismic energy that has evidently reshaped this asteroid [1].

This analysis has been generalized to explore the energetic stability of contact binary asteroids over a wide range of possible shapes and mass distributions [5]. Although simple models are used, we find profound results that can directly shape our understanding of the current NEA asteroid population, and which provides a link between the YORP effect and rotation rate distributions, the presence of contact binary asteroids, and the creation of orbital binary asteroids. As the angular momentum of a contact binary asteroid changes, we find a series of thresholds at which the minimum energy configuration of the asteroid can change drastically. If a body passes such a threshold it is susceptible to undergoing a large change in its morphology given a relatively modest input of energy. If the body's angular momentum continues to increase, a contact binary asteroid will fission directly into a relative equilibrium orbit configuration. Depending on the shape and mass distribution between the components, the system can either be stable and lead to a binary asteroid system, be unstable but bounded, preserving its contact binary structure, or be unstable and unbounded, leading to escape between the two components. For this last case, the energy of the initial contact binary asteroid has been increased to the minimum value possible that leads to such a disruption of the system.

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ASTEROID ROTATION AND SHAPE: GRAVITATIONAL AGGREGATE SIMULATIONS

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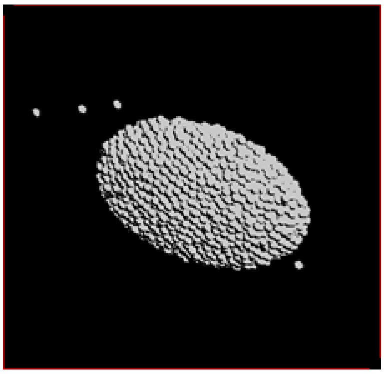
In the recent past, we used simulations of the gravitational collapse of a mono-disperse set of spherical particles for studyjng shape and spin properties of re-accumulated asteroid family members. The results show that only a category of shapes (flattened, two axis spheroids) are directly created. Moreover, they concentrate in specific regions of the spin/flattening plane. This numerical evidence is in contradiction with observations that show a variety of three-axial objects, scattered in a wide range of possible shape and spin combinations. Also, the theory of equilibrium figures predicts that three axial shapes should exist. The question of their origin is thus open. We will thus discuss two possibilities to solve this issue: an insufficient variety in initial conditions; spin changes and re-shaping induced by secondary impacts.



A SEARCH FOR SMALL ASTEROIDS IN THE COSMOS FIELD

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A certain population of sub-km asteroids are considered to have high inclination because they are selectively perturbed by the Yarkovsky effect. We have searched for small main-belt asteroids in the COSMOS (Cosmic Evolution Survey) field where the ecliptic latitude is about $-10°$ using Suprime-Cam mounted on the Subaru Telescope. A dedicated method was developed for this survey to detect small bodies in two images. By using it, we have detected more than 500 small bodies in 5 deg^2 with the limiting magnitude of i'=24.0 mag. Most of them are sub-km asteroid candidates. Estimated their orbital elements show the known spatial features, such as the Kirkwood gaps, two families, and secular resonance ν_6. Their number density is less than half of that at the ecliptic plane. The slope of the size distribution is 1.20 $\pm$ 0.04 for the asteroids with diameter of 0.4 km to 2 km, consistent with that of sub-km asteroids in the ecliptic plane. These facts do not indicate that the Yarkovsky effect acts effectively to asteroids larger than 0.4 km in diameter.

PHYSICAL PROPERTIES OF PRIMITIVE ASTEROIDS

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The progenitor asteroids of the different carbonaceous chondrites' groups were initially highly porous, but this microporosity decreased with time as consequence of internal heating, collisional compaction and aqueous alteration affected their primeval physico-chemical properties. This picture is fully consistent with recent laboratory experiments and microscopic and mineralogic studies. Most of the water was probably incorporated into the inner structure of the parent asteroids as ice, although some phyllosilicates would be have present in the nebula. However, there is growing evidence that most of the phyllosilicates present in these meteorites were formed into the parent asteroids. The low degrees of metamorphism experienced by these primitive asteroids is also shown by the mineral phases present in these rocks ($T < 1200C$). However, their texture suggest that many of them experienced compaction, brecciation, and shear, induced by impacts.

ROTATIONAL DISRUPTION OF COMETARY NUCLEI

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The distribution of measured rotational periods for cometary nuclei is non-random, with several very slowly rotating nuclei and an apparent cut-off of rotational periods at values less than ~5.3 hours. This cut-off is similar to what is observed for small asteroids, albeit at a different value for the period. In the case of the cometary nuclei, and assuming that the nuclei are strengthless rubble piles, the cut-off implies an upper limit on the bulk density of the nuclei of ~0.6 g cm^{-3}. It is likely that irregular outgassing of volatiles on the surfaces of the nuclei result in jet forces that can alter the rotational periods of the nuclei on each perihelion passage. Such forces are already known to alter the orbits of the returning short-period comets, including such prominent ones as 1P/Halley and 2P/Encke, and can also explain why some dynamically new long-period comets appear to be on hyperbolic orbits, when they actually are not. Rotational spin-up may also provide an explanation for random disruption of cometary nuclei. Currently, there is no satisfactory explanation for random disruption events. This work was supported by the NASA Planetary Astronomy and Planetary Geology & Geophysics Programs, and was conducted at the Jet Propulsion Laboratory under contract with NASA.