Protecting the Earth against Collisions with Asteroids and Comet Nuclei

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В сборнике представлены материалы Международной конференции по проблеме астероидно-кометной опасности, проходившей с 21 по 25 сентября 2009 г. в Институте прикладной астрономии Российской академии наук в Санкт-Петербурге. На конференции обсуждался широкий круг проблем, связанных с происхождением и физическими свойствами малых тел Солнечной системы, способных сталкиваться с Землей, обнаружением и слежением за подобными телами, разрушительными последствиями их столкновений с планетами и их спутниками. Особое внимание в представленных на конференции работах уделялось динамике сближения тел с Землей, предвычислению опасных сближений и организации защиты Земли от столкновений с достаточно крупными небесными телами.

Сборник рассчитан на специалистов в области изучения малых тел Солнечной системы и организации защиты Земли от катастрофических столкновений с небесными телами.

“Protecting the Earth against collisions with asteroids and comet nuclei”. Proceedings of the International Conference “Asteroid-Comet Hazard-2009”. A. Finkelstein, W. Huebner, V. Shor (Eds).

The volume contains the proceedings of the International Conference “Asteroid-Comet Hazard-2009” held in St. Petersburg, Russia, September 21–25, 2009. The conference was held in the Institute of Applied Astronomy of the Russian Academy of Sciences. The subjects of considerable discussion at the conference were the origin and physical nature of minor bodies of the Solar System that can collide with the Earth, detection and follow-up of such bodies and the devastating consequences of their collisions with planets and satellites. Special attention was paid to the dynamics of Earth approach of these bodies, predictions of dangerous collisions, and organization for protecting the Earth from collisions with dangerously large bodies (larger than about 25 m in diameter).

Papers presented in the Proceedings are of considerable interest for the Solar System science community and for all who are involved in study of small objects of the Solar System and in protecting the Earth against catastrophic collisions with celestial bodies.

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"Asteroid-Comet Hazard-2009"
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St. Petersburg, Russia

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Welcome Speech by A. M. Finkelstein, Director of the Institute of Applied Astronomy

Dear colleagues and friends!

I am happy to welcome you in Saint Petersburg to our conference "Asteroid-Comet Hazard-2009". More than 150 participants from 18 countries and from 135 different institutions will take part in the Conference, and they will present about 140 reports.

So large an attendance at the Conference shows that the problem of asteroid-comet hazard is a really vital and challenging scientific problem.

I would like to note that this Conference brings together specialists from many different fields of science, such as astronomers and physicists, geophysicists and geologists, engineers and designers, lawyers and even mass media. It shows how complex the problem of the asteroid-comet hazard is. One of the goals of this meeting is to strengthen cooperation and to build stable bridges between the specialists of different "colors" for better understanding and for improvement of studies.

It is well known that during four and half billions years the Earth was repeatedly exposed to collisions with asteroids, comet nuclei, and large meteoroids. The impacts of such cosmic bodies shaped the surface of the Earth and later created the conditions for the beginning and the evolution of life on our planet. These space phenomena caused global climatic changes, changes of flora and fauna, loss of thousands of living species and appearance of thousand of new ones including the mammalians and as a consequence man. A lot of interesting physical processes were connected with these phenomena and they attract the attention of many scientists.

One of the most practical questions of the asteroid-comet hazard problem is the question of how serious the risk of a collision of the Earth with an asteroid or a comet nucleus is, and what can be the consequences of this collision. This question concerns not only the specialists, but also the general public.

Our Conference should give answers to these questions and I hope that we will be able to summarize the most important answers for the mass media during a press-conference on Wednesday.

This Conference is held here in Russia, in the Institute of Applied Astronomy, which has worked for many years on the dynamics of small bodies

of the Solar System. In particular, you probably know, that the IAA publishes annually by order of the International Astronomical Union "Ephemerides of Minor Planets", which is distributed to different world astronomical institutions. Recently we started to use the VLBI-Network "Quasar" for observations of asteroids approaching the Earth. I hope that some of you will visit on Thursday the radio astronomical observatory "Svetloe", one of three observatories of the VLBI-Network "Quasar" which is situated in Leningrad Province, relatively near here.

This screen demonstrates all three "Quasar" observatories in on-line mode via optical fiber lines. They are situated in Leningrad Province, in the North Caucasus and near Baikal Lake in Siberia**.**

I hope that in 2011–2012, in accordance with our plans, we will put into service the large radar using the 70-meter radio telescope located in the Far East of Russia, which we are planning to use with the same aims.

I would like to mention that in Russia, the Russian Space Agency, the Russian Academy of Sciences, and some other governmental departments work together on the creation of various technical facilities for the observation of and development of countermeasures against asteroids and comets approaching the Earth. It is obvious that in order to design and to construct such facilities it is necessary to solve many complicated scientific and engineering problems, as well as, to coordinate a number of delicate juridical questions. It is clear that most of these problems can be solved as a whole only in the framework of international cooperation, using international resources.

We hope that our Conference will be the stimulus for the solution of all these questions.

The success of our Conference depends on the contributions of all participants.

Highly interesting and important contributions will be provided by oral and poster presentations and during discussions. As chairman of the Program Committee I would like to thank all the speakers and all the authors for preparation of their excellent presentations.

I would like also to express my thanks to members of the Program Committee who have set up a very interesting program.

Papers will be printed shortly after the Conference in Proceedings. Thanks to all — let us keep up the momentum and prepare our papers for the Proceedings in time.

I wish all participants to enjoy the Conference, useful meetings as well as a pleasant stay in our remarkable city.

Thank you!

Preface

The International Conference "Asteroid-Comet Hazard-2009 (ACH-2009)", organized on the initiative of the Institute of Applied Astronomy of RAS with financial support from the Russian Academy of Sciences and the Russian Fund for Basic Research, was held from 21 to 25 September, 2009, in St. Petersburg, Russia. The Conference is the most recent in a series of conferences about the same subject that are traditionally conducted by IAA RAS. Plenary sessions of the meeting were held daily in the IAA building in Kutuzov Quay, 10, with exception of 24-th September when an excursion to the radio observatory "Svetloe" on the Karelian Isthmus took place.

The Conference was attended by more than 140 participants from about 20 countries. About 70 oral presentations (13 Invited and 55 contributed papers) were presented during the Conference. In addition about 50 presentations were made in poster form. All oral reports were presented in seven sessions each pertaining to a certain subject. Names of the sessions are given bellow:

1. Small Bodies of the Solar System.
2. Observation and Detection of NEOs.
3. Comets: Physical Nature and Motion.
4. Meteor Complexes. Tunguska.
5. Devastating Consequences of Impacts. Study of Traces of Past Collisions.
6. Dynamics of NEOs. Collision Predictions.
7. Investigation of NEOs in situ. Counteraction to the NEO Hazard.

More than half of participants made use of the opportunity to submit their papers for publication in the Proceedings of the Conference. In the present Proceedings of ACH-2009 all papers accepted for publication are grouped in sections named for the sessions of the Conference. Every paper is put into the section to which it is related by subject. Every section begins with Invited presentations (in case they are published), these papers are followed by contributed oral communications. Each section ends with papers that were originally presented as posters. In each section papers are arranged in the order of their presentation at the Conference. To keep the size of Proceedings within reasonable limits, ten pages were allotted to invited papers, five pages for papers corresponding to oral presentations, and three pages for papers associated with posters, but this rule was not strictly enforced. An authors index placed at the end of the book facilitates finding of papers.

The papers presented for publication in the Proceedings were critically considered by Editors. In many cases the manuscripts were returned to authors for corrections, answering questions and correlating data. As we hope, this process has led to improving quality of papers included in the Proceedings. However, the editors also considered some papers for publication that were not fully mature for publication because they presented some novel and promising ideas that need considerable additional work. In all instances the papers reflect the authors' points of view even if they varied from standard accepted views or were at variance with that of the Editors. In case of some doubts upon correctness of results or proposed ideas the Editors preferred to give authors an opportunity to outline their results or ideas instead of rejecting the paper or insisting on complete correctness of the solutions. Only in small number of cases, when according to Editors' opinion the submitted exposition can lead to misunderstandings or wrong estimates of the attained result, the Editors take the liberty of inserting a footnote with an appropriate explanation.

It is not our aim here to give a comprehensive assessment of the Conference and those papers that appear in its Proceedings. Nevertheless, one will note that approximately three fourths of Conference participants came from countries of the former Soviet Union (FSU). By virtue of some selective process their papers comprise an even higher percentage in the Proceedings. Perhaps for the first time the papers of representatives of this geographical region on the subject of asteroid-comet hazard are collected in great diversity and completeness with Proceedings published in English. This provides an opportunity for English speaking readers to gain insight in the directions and levels of research in the field of asteroid-comet hazards that are conducted in the countries of the FSU. We hope that it also encourages international participation in the common defense of Earth against the asteroid-comet hazard.

Aside the geographical factors, the reader will hopefully find in the Proceedings a number of interesting ideas and developments regarding the study of small Solar System bodies, about problems of interaction of meteor matter with the Earth's atmosphere, and the study of the collision of the Tunguska space body and other space bodies with the Earth and other planets. At the ACH-2009 Conference (and to a lesser degree, in the Proceedings) research results devoted to catastrophic consequences of collisions of cosmic bodies with planets and their satellites were presented. Comprehensive expert information is presented on predictions of encountering dangerous celestial bodies with the Earth and other planets and on prospects for enlarging the scope of the Spaceguard survey to cover dangerous bodies of hectometer size. Finally, possible schemes of organization of Earth protection against

collisions with asteroids and comet nuclei are described in papers by several groups of researchers working on different continents.

Thus, in our opinion, the contents of the Proceedings is of broad interest for a wide section of researchers involved in the study of the problem of counteracting the asteroid-comet hazard, involving experts in the fields of physics, dynamics, the origin of small Solar System bodies, and meteor matter.

We are happy to use this opportunity to thank the members of the Scientific Committee and members of the Local Organizing Committee of ACH-2009 for organization and successfully carrying out the Conference and for co-operation during publication of its Proceedings. We are especially indebted to Diana Ryzhkova, staff member of the IAA RAS for preparation of the Proceedings and to the staff of the St. Petersburg branch of the Publishing house of RAS for preparation and publication of the Proceedings. We also thank Yurij A. Bondarenko, the author of several papers incorporated into the Proceedings, for designing the Conference logo presented on the Proceedings cover.

Andrey M. Finkelstein, Walter F. Huebner , Viktor A. Shor


Standard scenario of evolution of gas-dust pre-planetary disk around the early Sun

Part 1. Small Bodies of the Solar System

SMALL BODIES OF THE SOLAR SYSTEM

Physical Properties and Internal Structure of Near-Earth Objects

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Abstract. The review contains the most recent data on near-Earth objects such as their sizes and densities, rotation and shapes, taxonomy and mineralogy, optical properties and structure of their surfaces, binary systems among the NEOs and internal structure of asteroids and comets constituted the NEO population. The European space mission ISHTAR for investigation of NEOs 4660 Nereus and 5797 Bivoj, which is planned to be launched in Sept. 2011, is briefly described.

Introduction

Near-Earth objects (NEOs) are defined as asteroids and comets having orbits with perihelion distances of 1.3 AU or less. About 30 % of the entire NEO population may reside in orbits having a Jovian Tisserand parameter < 3, and among them roughly half are observed to have comet-like physical properties such as albedos and spectra. Thus, about 10–15 % of the NEO population may comprise extinct or dormant comets [1–3]. The rest are the near-Earth asteroids (NEAs). They are traditionally divided into three groups (the relative abundances are estimated by Bottke et al. [4]):

Amor	$a \geq 1.0$ AU	$1.017 < q \leq 1.3$ AU	$(32 \pm 1$ %)
Apollo	$a \geq 1.0$ AU	$q < 1.017$ AU	$(62 \pm 1$ %)
Aten	$a < 1.0$ AU	$Q > 0.983$ AU	$(6 \pm 1$ %)

Besides these, there is an additional group of rather dangerous asteroids whose orbits reside entirely inside of the Earth's orbit (Q < 0.983 AU). According to [5] objects of this inner-Earth asteroid group and Aten group together can constitute about 20 % of the km-sized Earth-crossing population.

About 6600 NEOs were discovered by the beginning of November 2009. They are the objects of special interest not only from the point of view of basic science, but also of applied science (the problem of asteroid and comet hazard, the NEAs as the potential sources of raw materials in near Earth space, etc.).

Sizes, densities and axis rotation

In general NEOs are much smaller in size in comparison with main-belt asteroids. The size distribution of NEO population can be approximated as

$$N\,(>D\ \text{km}) = k\,D^{-b}$$

with an exponent $b = 1.95$ and $k = 1090$ [6].

This expression indicates that there are 1090 NEOs with $D \geq 1$ km. Including uncertainties, Stuart and Binzel [7] give this result as 1090 ± 180 objects that are 1 km or lager within the NEO population, which agrees well with previous estimates. Below, the sizes of some individual objects are presented that display the whole range of sizes of cataloged NEOs overlapping four orders of magnitude.

Largest NEOs		Smallest discovered NEOs	
1036 Ganymed	$D = 38.5$ km		
433 Eros	16.5	2000 *WL*107	$D = 38$ m
3552 Don Quixote	12÷15	2003 *QB*30	17
1866 Sisyphus	8.9	2003 *SQ*222	10
		2008 *TC*3*	4

* Discovered on 6 Oct. 2008, collided with the Earth on 7 Oct. 2008 and disintegrated in the atmosphere over northern Sudan.

Below, the most reliable estimates of bulk densities (g/cm^3) for S, Q, and C-type NEOs are summarized. Discovery of binary NEOs gives a good opportunity to determine their bulk densities, however those estimates are usually not accurate enough due to an uncertainty of binary system parameters.

433 Eros"	2.67 ± 0.03	S
6489 Golevka*	2.7 (+ 0.4, –0.6)	Q
25143 Itokawa"	1.95 ± 0.14	S, Q
1999 *KW*4*	1.97 ± 0.24	S
2100 Ra-Shalom*	1.1 – 3.3	C
1996 *FG*3	1.4±0.3	C
2000 *DP*107	1.6 (+1.2, –0.9)	?
2000 *UG*11	1.5 (+0.6, –1.3)	?

" Space mission data; * Radar data.

Comparing bulk densities of these NEOs with densities of their meteorite analogues (ordinary or carbon chondrites) we have to suppose about 30–50 % porosity of NEO. The 4-m F-type NEO 2008 *TC*3 that disintegrated in the atmosphere (but some pieces were found) displayed also about 50 % porosity. It means that at least some of NEOs are not monolithic bodies but "rubble-pile" structures, which have no coherent tensile strength and are held together weakly by their own mutual gravity. One example of such bodies is the Apollo-object 25143 Itokawa [8].

The distribution of the spin rates of NEOs (Fig. 1) is quite different in comparison with that of small main-belt asteroids (MBAs) and it shows the prominent excesses of slow and fast rotators [9]. Among the reasons for that may be the difference in asteroid diameter distributions within these two populations, influence of the radiation pressure torques (YORP-effect), the influence of the rotational parameters of binaries and may be some selection effects. The whole interval of NEO spin periods ranges over four orders of magnitudes from 500–600 h (96590 1998 *XB* and 1997 *AE*12) to 1.3 min (2000 *DO*8). It is clear that such small (a few 10 m in size) and super-fast spinning bodies are beyond the rotational breakup limit for aggregates like "rubble piles" and therefore they are monolithic fragments.

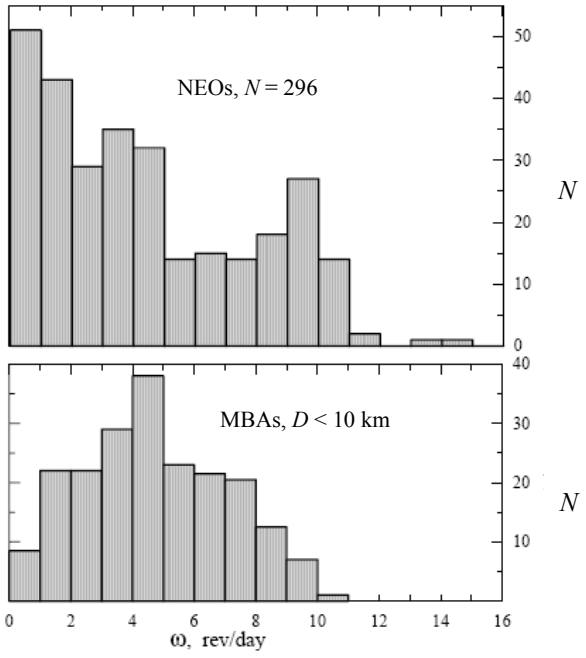

Fig. 1. Distribution of the spin rates of NEOs and small ($D \leq 10$ km) main-belt asteroids.

Taxonomy and mineralogy

As a first step toward estimating the nature of any NEO is determination of its taxonomic class, that is, the object's total mineralogy. Practically all taxonomic classes identified among main-belt asteroids have also been found in the NEO population, including the C, P and D classes that are typical of the outer main belt. Binzel et al. [10] from their spectroscopic survey of 252 NEAs and Mars-crossers noted that 25 of 26 Bus' taxonomic classes [11] of main belt asteroids were represented in the NEO-population. The most common taxonomic classes among them are however S and Q (silicate) types. Recent spectroscopic investigation of 150 NEAs [12] have summarized that 62 % of them belong to S-complex, 20 % to X-complex, 12 % to C-complex, and 6 % to other classes of Bus' taxonomy. Stuart and Binzel [7] modeled the bias-corrected distribution of taxonomic classes and concluded that C and other low-albedo classes constitute 27 % and S + Q classes 36 % of all NEOs.

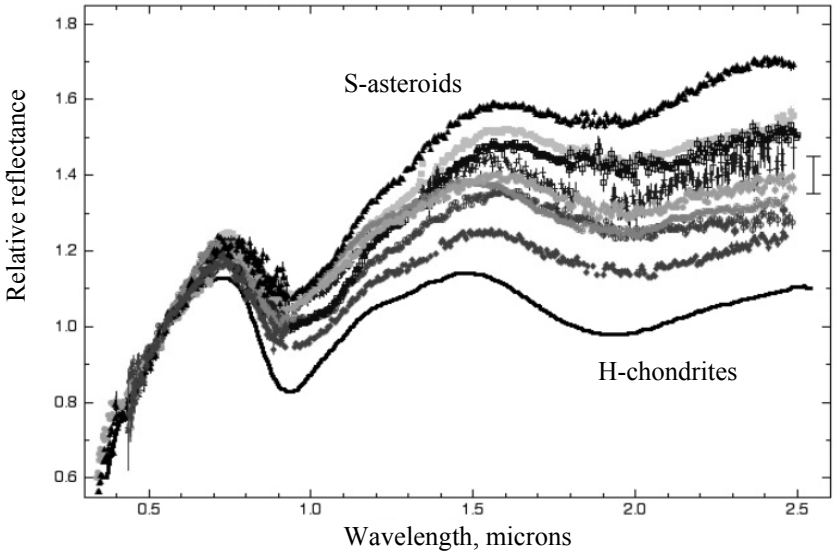

Fig. 2. Continuous range of NEO spectra from S-types to ordinary H-chondrite meteorites (that is, to Q-types) [13].

Observing smaller and smaller *S*-objects Binzel et al. [13] showed a continuous range of NEO spectra from those of *S*-types to ordinary chondrites (Fig. 2). That is, there is a continuous transition from spectra of S-types to those of Q-types. At the same time Q-objects are smaller in size and brighter than S-objects, that is, their surfaces are "younger, fresher". Therefore, this continuum is interpreted as a result of space weathering

process, that is, the process of alteration of the young surface of Q-asteroid to look more and more redder like S-type surfaces [10]. Lazzarin et al. [12] found that only 17 % of NEOs and 6 % of MBAs are compatible with ordinary chondrite spectra but other objects are much redder. They also found the statistically valid linear increase of spectral slope with increase of asteroid exposure (that is, amount of Sun's radiation that a body receives along its orbit), which supported the idea of space weathering. Fevig and Fink [14] reported the results of spectrophotometry of 55 NEOs which revealed the statistically significant evidence for orbit-dependent trends in their data: while observed S-types reside primarily in Amor-Apollo-Aten orbits which do not cross the asteroid main belt, the majority of objects with spectra consistent with ordinary chondrites (Q-types, that is, fresh and relatively unweathered NEOs) are in highly eccentric Apollo orbits that enter the asteroid main belt. It is very likely that these objects have recently been injected into such orbits after a collision in the main belt.

Optical properties and surface structure

The analysis of available data clearly demonstrates that the surfaces of NEOs display in general the same optical properties as the surfaces of MBAs [9, 15, 16]. The whole range of NEO albedos (0.05÷0.50) is basically the same as that of MBAs and it corresponds to the same in general mineralogy within these two populations. But the strict similarity of the other photometric and polarimetric parameters (such as phase coefficient, polarization slope and others, that are related to surface structure) gives evidence of the similar surface structures on a submicron scale.

The polarimetric, radiometric data and direct imaging of Eros and Itokawa give evidence that most NEOs are covered with regolith (fine granulated rocks and dust). Despite their low gravities, even the smallest NEOs appear capable of retaining some regolith coating. As it was estimated a minimum 2.3 ± 0.4 m thick layer of regolith exists in the lowlands of Itokawa, which, if spread evenly across the entire asteroid, corresponds to a 42 ± 1 cm layer. The recent studies of NEO thermal IR emission showed that the average thermal inertia of km-size NEOs is 200 ± 40 $\mathrm{Jm^{-2}s^{-0.5}}K^{-1}$, that is about four times that of the Moon [17]. Furthermore, those authors identify a trend of increasing thermal inertia with decreasing asteroid diameter.

Radar observations showed that even the relatively small NEOs 4179 Toutatis and 1999 *JM*8 ($D \sim 3$ km both) are cratered about to the same extent as MBAs 951 Gaspra and 243 Ida. The radar data also showed evidence that NEO surfaces are rougher than surfaces of large MBAs on the length scale of decimeters and meters. Recently the radar observations have also revealed a link between NEO composition and surface roughness. As is

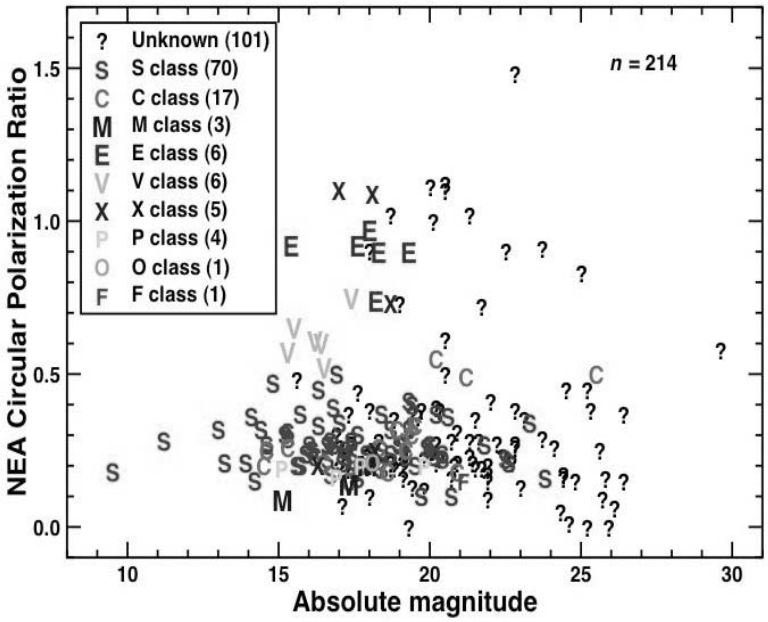

Fig. 3. A radar link between composition and surface roughness (*http://echo.jpl.nasa.gov/*).

clear from Fig. 3 the objects of different composition types have different radar circular polarization ratios, which characterize a measure of centimeter-to-decimeters surface roughness. The roughest are the high-albedo objects of E and V-types, the meteorite analogs of which are enstatite chondrites and HED-meteorites (basalts), and they are most probably rougher because of higher material strength.

Binary and triple systems among the NEOs

By the beginning of November 2009, 37 binary near-Earth asteroids (one with two satellites) have been discovered. They show the similarity of their parameters, for example, spin periods of primaries are within the interval of 2.3–3.6 h and orbital periods of secondaries are in the range of 0.5–1.8 days (which may be due to observational selection effects). A fraction of binary systems among the NEAs is estimated to be 15–17 % [18], though among the Aten-asteroids the fraction can be significantly higher [19].

The NEA 2001 *SN*263 has been revealed as the first near-Earth triple asteroid ever found. It was discovered by Mitchal Nolan and his colleagues using the Arecibo radar. The central body is spherical of $D \approx 2$ km across,

while the larger of the two moons is about half that size. The smallest object is about the size of the Arecibo telescope. Pravec and Harris [20] suggest that binaries formed from parent bodies spinning at the critical rate by some sort of fission or mass shedding, and the YORP-effect is a candidate to be the dominant cause of spin-up to instability. This suggestion is in a good agreement with results obtained by Walsh and Richardson [21] that tidal disruption due to close planetary encounters should account for about 1–2 % of binary NEAs and that there are other formation mechanisms that contribute significantly to this population.

Discovery and study the binary or triple systems allows one to determine the density of the NEOs and type of their material.

On the internal structure of NEOs

The internal structure of NEOs is key information to planning a mitigation strategy. Unfortunately, there are only indirect data on the internal structure of NEOs such as bulk densities and porosities, their spin rates, the events of comet nuclei disintegration, existence of large craters, crater chains and grooves on asteroids and satellites, and the recent data from the Japanese space mission Hayabusa to asteroid 25143 Itokawa. Campo Bagatin [22] analyzed these indirect evidences in order to extract information on the internal structure of NEOs. Taking into account the results of his analysis one can summarize the following.

- The estimated bulk densities of S and especially C-type NEOs (see [9]) are well below the density of their meteorite analogues, which suggests 30–50 % NEO macroporosity. Such porosity can result if a body is completely shattered and reassembled, creating a gravitational aggregate (GA). It means that some NEOs are not monolithic bodies but “rubble-pile” or GA structures, which have no coherent tensile strength and are only weakly held together by their own mutual gravity.
- Comet nuclei also show surprisingly low bulk densities: 0.1–0.5 g/cm^3 (Churyumov–Gerasimenko), 0.18–0.36 g/cm^3 (Borrelly), 0.36–0.76 g/cm^3 (Tempel 1), 0.26 ± 0.15 g/cm^3 (Halley). For these comets bulk porosities (that is, macroporosity) on the order of 70 to 80 % would apply [22]. For example, in July 1992 Shoemaker–Levy 9 passed very close to Jupiter inside the tidal breakup (Roche) limit for unconsolidated water ice and its nucleus was disrupted into many fragments. The estimated tidal stress on the inferred parent body is found to be very small (~10^4 bar). It means that before breakup the nucleus was very likely an incoherent aggregate of fragments. Several other tidal disruptions and even spontaneous nucleus splitting of comets are known (e. g., C/1999 S4 LINEAR, Schwassmann–Wachmann 3).
- In spin periods of 1–10 km sized asteroids, Harris and Pravec [23] have found a “spin rate barrier” — the lack of periods less than 2.2 h (spin

faster than ~11 cycles/day). It suggests that even such small asteroids are GA or "rubble-piles", that is, with no substantial tensile strength. At the same time some much smaller objects ($D \leq 100$ m) show a super fast spin with periods ~2 minutes; this is much faster than the "spin barrier", indicating that they are monolithic bodies with sufficient tensile strength.

- The existence of relatively large craters ($d_{\text{crater}} \sim R_{\text{object}}$), grooves, doublet craters, and crater chains on asteroids and satellites also suggests processes of body disruption with subsequent reassembly of fragments creating a GA. In particular, the absence of any correlation between the inferred parent body mass and the number of craters in the chain supports the idea that the fragments reaccumulated via gravitational instability just prior to impact [22].
- NEO 25143 Itokawa is considered as the most striking example of GA, when considering its density, which corresponds to about 40 % of void space (macro-porosity), an availability of large blocks (boulders) on the asteroid, and other evidence of a catastrophic disruption scenario for the formation of Itokawa.

Thus, the NEO population presents at least three very different types of body internal structures. They are: a) monolithic objects (the fragments of larger parent main-belt asteroids) including the metal ones with a tensile strength of about 10^9 dyn/cm^2; b) the structures of "rubble-piles" type or GA; c) about 10 % [1–3] of extinct or dormant comet nuclei with a tensile strength of about 10^2–10^3 dyn/cm^2.

Summary

The European Space Agency works on a NEO space mission preparation named ISHTAR (Internal Structure High-resolution Tomography by Asteroid Rendezvous). Its program foresees the investigation of Apollo-object 4660 Nereus (C-type, $D \sim 1.2$ km) and Amor-object 5797 Bivoj (S-type, $D \sim 0.5$ km) with determination and study of:

- mass and bulk density of target NEOs;
- internal structure, mass distribution, detailed shape;
- spin rate including axis orientation and precession (if any);
- detailed surface geology, characterization of regolith, etc.

Mission ISHTAR will be launched in Sept. 2011 with a Ukrainian Dnepr rocket to reach 4660 Nereus in 2014. After a stay at Nereus of nearly 15 months, during which extensive science measurements can be performed, ISHTAR will then transfer to asteroid 5797 Bivoj in order to repeat the same type of science measurement during a period of at least 3 months. The total mission duration is approximately 7 years.

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