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"
September 21–25, 2009,
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

Masses of asteroids 10 Hygiea and 152 Atala obtained by the dynamical method

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Abstract. Masses of asteroids 10 Hygiea and 152 Atala have been obtained by the dynamical method. Some other asteroids were used as test particles. We evaluated the contributions from different perturbing asteroids and the additional acceleration caused by the Yarkovsky effect in determining the masses. The influence of different criteria for elimination of erroneous observations on the value of determined mass was studied. The final mass values were obtained by common solutions based on optical observations of eight perturbed asteroids for 10 Hygiea [$m_{10} = 4.03 \pm 0.10$ (10^{-11} M_{Sun})] and of three perturbed asteroids for 152 Atala [$m_{152} = 1.34 \pm 0.27$ (10^{-11} M_{Sun})].

Introduction

This paper deals with problems of asteroid mass determination by the dynamical method when some other asteroids are used as perturbed bodies. The main parts of this approach are: a) appropriate model of motion; b) choice of perturbed asteroids; c) elimination of erroneous observations.

Choice of perturbed asteroids was made in accordance with the approach proposed in the paper [1]. The approach is based on the value of the mass error of perturbing asteroid obtained from observations of each perturbed asteroid. This criterion implicitly incorporates such often used criteria as value of minimal distance between bodies, number of close approaches, number of observations of perturbed asteroids and so on. However, some small values of mass error correspond to nonrealistic (very large or negative) mass estimations.

Therefore we try to investigate what factors have influence on the obtained mass values. It is proposed to evaluate contributions of: a) different sets of perturbing asteroids; b) different criteria of elimination of erroneous

observations; c) additional acceleration due to the Yarkovsky effect. Also it is not quite clear what kind of the perturbed asteroids are more preferable: if perturbed asteroid is rather large, the mutual perturbations should be taken into account; if perturbed asteroid is small, then there is a possibility of influence by the Yarkovsky effect on the mass estimate. These questions were considered in the evaluation of masses of asteroids 10 Hygiea and 152 Atala.

Results

Perturbed asteroids (PAs) were selected from the numbered asteroids in accordance with values of the mass errors of perturbing asteroid obtained from observations of each PA. Optical observations were taken from MPC catalogue. We have used observations starting from 1900.

Calculations were fulfilled using two independent software programs ("IAA" and "Nikolaev" [2]), however, models of motion and the sample of observations were the same. The gravitational perturbations from all the major planets and Pluto were taken into account. The coordinates of the main perturbing bodies were calculated using DE405 ephemeris. Relativistic perturbations from the Sun were included into the model. The possibility of accounting perturbations from: a) Ceres, Pallas, and Vesta; b) 300 asteroids in accordance with DE405; c) 307 asteroids (300 asteroids and large asteroids 152, 153, 190, 279, 334, 675, 1180) were considered. The phase correction and the gravitational deflection of light were taken into account. Numerical integration of the equations of motion and variation equations was performed by the 15th-order Everhart method. Erroneous observations were rejected by the 3 σ criterion ("IAA") or by application of a robust regression ("Nikolaev"). The final mass values have been defined by common solutions using observations of a number of selected PAs for each perturbing asteroid. The least squares method was used to fit conditional equations. Two variants of weights were used: a) equal weights; b) the weight 0.7 was given for all observations made before 1950.

Distributions of masses of perturbing asteroids and their mass errors versus diameters of perturbed asteroids show the advantage of large asteroids because they produce the lesser range of the mass values and the lesser mass errors as compared with small asteroids. It may be the result of the smaller mean residuals of these bodies, the larger intervals of observations, or the greater number of approaches. Hence the large perturbed asteroids (d > 150 km) can give a useful contribution to mass determination. However, it is necessary to take into account that mutual perturbations of perturbed and perturbing asteroids can be considerable. It should be noted that this conclusion was obtained for perturbing asteroids having diameters 429 and 287 km.

A number of common solutions were obtained for the mass of Hygiea. All of them are in good agreement with each other. We give here the mass

value 4.03 ± 0.10 (10^{-11} M_{Sun}), which was found using eight numbered PAs: 20, 3946, 6143, 11215, 15187, 24433, 48499, and 113976. The mass of 152 Atala 1.34 ± 0.27 (10^{-11} M_{Sun}) was found using observations of PAs 250, 264, and 651.

The estimates of a possible influence by additional acceleration from the Yarkovsky effect on the mass value were obtained for some PAs (see Table). We determined orbital parameters, mass correction and the transverse component of the acceleration, A_2, on the assumption that its value depends on the heliocentric distance as $1/r^2$. It should be noted that the so determined parameter A_2 can include not only the Yarkovsky effect but also some other accelerations not taken into account explicitly.

Estimates of mass of Hygiea (the third column) and estimates of its mass together with additional acceleration A_2 (the fourth column)

Perturbed asteroid	Diameter, km	M, 10^{-11} M_{Sun}	m, 10^{-11} M_{Sun}	A_2, 10^{-14}AU day^{-2}
3946	13.6	4.05 ± 0.16	3.41 ± 0.29	–33.5 ± 13.3
15187	6.5	3.52 ± 0.54	3.47 ± 1.13	–1.2 ± 3.4

Conclusions

- The mass values of asteroids 10 Hygiea and 152 Atala were obtained: m_{10} = 4.03 ± 0.10 (10^{-11} M_{Sun}), mean density = 2.0 g·cm^{-3};
  m_{152} = 1.34 ± 0.27 (10^{-11} M_{Sun}), mean density = 2.8 g·cm^{-3}.

The mass obtained for Hygiea is close to its value, 3.7 (10^{-11} M_{Sun}), assumed when constructing DE405.

- Final mass values practically do not depend on the criterion of rejecting erroneous observations.
- It was shown that mass estimates depend on completeness of accounting for perturbations. Therefore accounting for perturbations from asteroids should be as complete as possible.
- The additional acceleration acting on some perturbed asteroids was evaluated. It seems to be useful to include in the common solution the unknown parameter A_2 for each relatively small perturbed asteroid, in addition to the orbital parameters and mass correction.

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