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ON THE NATIONAL PROGRAM OF COUNTERACTION SPACE THREATS

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Abstract

We present a brief overview of the current state of activities in Russia on the space threats problem. Major attention is paid to the concept of a system for prevention the threats. The system will address two kinds of space threats: asteroid/comet impact hazard (ACH) and space debris. Participation of number of ministries and organizations is foreseen. As it concerns NEO problem the main line is to construct the efficient system of detection and monitoring the dangerous bodies. . Roscosmos gave start for construction of such a program in November 2012. The major elements to be constructed (or modernized) are: detection facilities both ground-based and space ones; monitoring (follow up) facilities; information analytical center. These constituents are briefly described in the paper.

An initiative on a construction of data-bank of impact consequences such as geographical, economical etc. is briefly announced in the report. The suggestion is to pre-calculate the consequences for all the most “sensitive” (to the ACH) regions on the Earth during “quiet age” (before the next serious collision). This will speed up and facilitate decision-making process. It is clear that for some countries it will be problematic to construct an own part of the relevant data bank. A dedicated international program would be helpful.

1. INTRODUCTION

Life and the human civilization on the Earth exist in the environment of cosmic threats. Some threats are of a natural origin. These are relatively rare dangerous events of space weather anomalies (one event in a few decades), asteroid/comet impact hazard (typical time interval - centuries), and much more rare astrophysical catastrophes in the vicinity of the Solar system (e.g. stellar explosions), as well as possible biological invasions. The space debris problem and the menace of contamination by the return of biological species (dangerously changed by poorly known space factors) are problems that are considered as an inevitable consequence of human propagation in space. In various circumstances various threats attract public attention and become most “popular”.

For obvious and everyday practical reasons, space debris remains a space threat, attracting major attention of nations during the last fifty years (i.e. over the cosmic era). As a result we have substantial progress in the construction of specialized instruments and networks aimed to detect and monitor space debris. Radar and optical detectors, including lasers, are the main tools used for tracking space debris. Radars are most efficient for LEO objects. Optical instruments are more efficient for the observation of space debris fragments at distances larger than 5000 km. About 20 000 objects are catalogued at the moment. Nevertheless, the majority of debris objects remain unobserved. There are more than 600,000 objects larger than 1 cm (0.4 in) in orbit (according to the ESA Meteoroid and Space Debris Terrestrial Environment Reference, the MASTER-2005 model).

The Asteroid-Comet Impact Hazard (ACH) problem (more frequently abbreviation NEO problem is used) has become, in recent years, a very topical subject. This is due to the fact that the specialized programs of observations have resulted in a sharp increase in the efficiency of discovering such bodies, and new information compels one to have a new look at the ACH problem. Along with specialized scientific conferences, public discussions on the ACH problem are led by the UN, governments and parliaments of some countries and nongovernmental organizations. The leading countries began to invest considerable funds in the technology of discovery and monitoring the object approaching the Earth, as well as to counteracting the hazard of collisions of such bodies with our planet.

The asteroid/comet hazard is a risk for mankind to have serious damage, due to collisions of natural celestial bodies (i.e., asteroids and comets) with the Earth. The lower boundary of dimensions of a hazardous body is determined as ~ 50 m. There are three reasons to keep along this size definition. First two reasons are obvious. The average estimate of the energy released at a collision of a body of this size is comparable to the energy of the most powerful explosion ever fulfilled by man on the Earth. Secondly collisions with bodies of this size are most frequent. Thirdly, as it was demonstrated in [1], where consequences of collision with bodies of various size were numerically simulated in, there is a maximum of specific efficiency of the destruction (total devastation area per mass unit of colliding body). The maximum corresponds to the size of the asteroid about 50 meters (for vertical entry). In terms of the impact this scenario corresponds to the boundary between the surface and the aerial "meteor explosions."

NEO are detected with optical and infrared instruments. Most of the NEO observations were performed with optical telescopes. Recently, the infrared 40-cm space telescope WISE has demonstrated the high effectiveness of infrared instruments [2]. Radars are powerful for characterization of large and close asteroids and comets, but they cannot be used for detection. Up to now only a few hundreds of the objects were observed [3]. Contemporary completeness of our awareness about threatening NEOs is approximately at same level as for space debris. The total number of potentially hazardous NEOs larger than 50 m is estimated as some hundreds of thousands. Only about 1% of them have been detected! Thus, the first task both for space debris and NEO is a massive detection of the objects.

As far as it concerns detection and monitoring of threatening objects with optical instruments, the solution of space debris and NEO problems require to some extent similar approaches. Therefore, it seems to be logical to consider both problems in a consistent way.

In this paper we briefly review the current state of studies on the ACH hazard problem in Russia (section 2). Special attention is drawn to the necessity of implementation of the ACH technical and organizational approaches in the being created elements of (inter)national space situation awareness system – especially in the broadly discussed (international) Information, Analysis and Warning Network (IAWN). Russia was and will be an active participant in the UN activity on the NEO problem either. An example of an international initiative proposed by Russia, i.e. the initiative on a construction of data-bank of impact consequences is described in section 3. Conclusions are given in section 4.

Let us remind that this brief review mostly refers to the state of the art of the ACH problem in Russia, so numerous important papers and documents by the researchers of the international NEO community are not mentioned here.

2. STATE OF ART OF STUDIES OF THE ACH PROBLEM IN RUSSIA

An increasing activity of studying the ACH problem is noted in the scientific and industrial communities of Russia. In order to coordinate investigations in the field, the "Expert Working Group on the problem of asteroid/comet hazard problem" was established in February 2007 by the Space Council of the Russian Academy of Sciences. In 2011 the group was transformed into "Expert Working Group on Space Threats". Coordination of the fundamental research on the ACH and space debris issues is considered as a primary task of the group. This group includes representatives of the Russian Academy of Sciences (RAS), major universities, Federal Space Agency of Russia, Emergency Committee, Rosatom, Ministry of Defense, and other concerned ministries and organizations. Some materials about the activities of the Expert Group are presented at its website *http://www.inasan.ru/eng/asteroid_hazard/.* The main practical task of the group is to elaborate a concept of a dedicated national (federal) program.

At PDC-2011 we argued for the development of the national program to counteract space threats. The national program is considered as a good basis for establishing an efficient international cooperation. Encouraging examples of the national programs are provided by NASA's NEO program and European SSA program. We believe that for the effective participation of Russia in the international cooperation on the NEO problem, we have to develop a comprehensive national (federal) program. The arguments pro national (federal) program are clear:

1. The NEO problem is a multi-problem. Various organizations are to be involved (coordinated);
2. The capabilities of research centers are not sufficient for implementation and support of the modern service of detection and monitoring of NEO, in particular those requiring space facilities;
3. The expensive technologies of preventing collisions and mitigation can be proposed, but not be implemented under the responsibility of any separate research institutions;
4. Cooperation of countries on the NEO problem implies the involvement of the Russia Government (or authorized body);
5. National program means regular funding. This is absolutely necessary for the realization of a real program.

The major elements of the concept of the long-term program are presented in [4].

In the past three years the idea o the national program has got a practical development in Russia. In June 2010 a special joint meeting of the heads of the Federal Space Agency (Roscosmos) and the Space Council of the RAS. The draft concept was presented at the meeting and positively considered. Roscosmos and RAS expressed their wish to integrate issues of NEO and space debris in the Federal Program. By the way, this decision demonstrates that the approach used to establish, the European Space Situational Awareness System [5] was considered with attention.

There are three basic aspects to be recognized in the ACH problem:

- Detecting, determining the properties of, and assessing the risk from hazardous celestial objects.
- Protection and damage reduction.
- Having a cooperative approach.

We briefly describe the blocks of the national program that are "responsible" for these issues of the ACH problem.

2.1. Detection and monitoring

In November 2012 an important step was made in Russia towards establishing a space situational awareness program aimed to reveal and counteract the space threats (including asteroid/comet impact hazard). Roscosmos gave start of systemic approach to elaboration of program of construction the system of detection and monitoring dangerous objects (space debris and NEOs). Two major partners are considered: Roscosmos - for space debris and Russian Academy of Sciences - for ground based facilities for detection and studies of NEOs. Roscosmos is considered either to be in charge for all the NEO related space missions. This seems to be first and most important step to the construction of a national system. In following subsections we briefly comment on the major aspects of the system.

<u>Detection.</u>

Two modes of detection are considered:

- Large Distant Detection (LDD). Major goal is to detect hazardous bodies larger than ~ 50 m well beforehand. This requires powerful instruments and sufficient time for detection and characterization (orbit determination).
- Near Earth Detection (NDD). Major goal – to detect bodies: meteoroids and space debris in near space (say inside lunar orbit) meteoroids. This mode requires for not so powerful telescopes as LDD does but the instruments should be very fast.

A major difference between the dangerous populations of NEOs and space debris are listed in table 1. Typical values of the parameters are given. Only those parameters are included that are important for detection and monitoring of the objects with optical instruments. The meteoroids like that entered February 15, 2013 in the Earth atmosphere near Chelyabinsk can be compared with largest objects of space debris, though their velocities are somewhat larger in general.

Table 1. Comparision of NEO and space debris populations.

Objects *Parameter (typical values of)*	Dangerous NEOs	Dangerous fragments of space debris
Size	> 50 m	> 1cm at LEO > 5 cm at GEO
Albedo	0.1 for asteroids 0.3 for (young) comets	wide range
Linear velocity at approach to the Earth	20 km/s for asteroids up to 71 km/s for comets	8 km/s at LEO 3,2 km/s at GEO
Angular velocity	< 10^{-5} deg/sec at distance 1 A.U.	< 1 deg/sec at LEO 0,005 deg/sec at GEO
Stellar magnitude	V < 23 – 24^m	V < 19 – 20^m
Spatial distribution	Asteroids at large distances - concentrated to ecliptic plane Comets and asteroids at approach – almost uniformly over celestial sphere.	at LEO – almost uniformly over celestial sphere. at GEO – concentrated to the GEO.

The parameters in Table 1 (especially those in the last three lines) are essentially the basic technical requirements for the design and construction of efficient instruments for detection and monitoring threatening objects. As we can see from table 1 the major difference between NEO and space debris population is the much higher angular velocity of the typical space debris fragment in comparison with an asteroid or comet. Image smearing prevents getting a high signal-to-noise ratio for space debris, but this is compensated (to the some extent) by a higher typical brightness of the space debris fragment in comparison with the small NEO. Naturally, the instruments (telescopes and cameras) are similar for both classes of objects for NDD mode.

The major requirement for the LDD-system that ensures massive detection of potentially hazardous bodies can be formulated in simple words as follows:
A given share (typically not less than 90%) of NEOs, that are large enough to make a serious harm for humankind as whole or for individual countries (typical size of such a body exceeds 50 m), should be detected timely (typically required warning time must be not less than 30 days).

Having in mind that observed and estimated rapprochement velocities for NEOs do not exceed 40 km/s, and the extra time (typically up to 7 days) is required for the reliable classification of the object as a dangerous one since the first observation, we get that the detection system should massively discover NEOs with absolute (asteroid) magnitude $H < 23$ (see for details [6]).

There are a lot of astronomical instruments over the world. Some of them are huge, some are wide field, but very few of them (at the moment PS1 only [7]) are capable to solve the detection task.

In the draft concept of the national Program, we consider construction of new optical instrument(s) for massive discovery of the NEOs. First of all we need to complete construction of the wide field 1.6 m telescope at the Institute of Solar-Terrestrial Physics, Siberian Branch of the RAS [8] (see Fig. 1.)

Spectral range	400-1100 nm
F	5600 mm
focal ratio	1:3,5
2ω	$2,8^0$
2y’	277 mm

Fig. 1. The project of 1.6 m wide field telescope AZT-33VM: designer view and major parameters.

Space based telescopes are powerful instruments for detecting and characterization of hazardous bodies. A brief review of existing facilities and some project under design and/or construction over the world is given in [4]. In [9] we present on of the Russian projects of a space system for the detection of NEOs. This is a low cost space project with 75-cm aperture wide field (7° FOV) telescope of original design by V.Terebish.

For the NDD mode system analogous to ATLAS (The Asteroid Terrestrial-impact Last Alert System) (see http://www.ifa.hawaii.edu/info/press-releases/ATLAS/) seem to be prospective.

Monitoring:
The monitoring (follow up observations) is a key factor for the proper characterization of the hazardous object. The national program includes the plan to establish a network for the follow-up observations of the discovered NEOs and especially of the potentially hazardous objects (PHOs). There exist premises for this. To mention some: programs of observations of NEOs are being performed at Pulkovo Observatory (RAS), in the Institute of Solar-Terrestrial Physics (RAS), Special Astrophysical Observatory (RAS), Kazan University (with 150-cm telescope elevated in Turkey), and Institute of astronomy (RAS) with 2m telescope at Terskol observatory, etc. There works efficient observational network ISON established Institute of Applied Mathematics of the RAS and financially supported by Roscosmos. ISON is developing and internationally demonstrating its efficiency for space debris studies [10]. It expands the observational program to NEOs. These facilities, as well as specially designed ones, are suggested to constitute the national network. The task is not easy, mostly because of organizational difficulties, but again we are encouraged by the good examples of organizations of effective (inter)national observational programs in the US and Europe.

3. Data handling:
Thre are three world known data centers for NEO problem. The collection, processing, storage and dissemination of information on the observed positions of NEOs is currently being carried out by the Minor Planet Center operating at the Smithsonian Astrophysical Observatory in Cambridge, MA, USA,. The prediction of motion of potentially hazardous objects, the search for their close approaches to Earth, and the estimation of impact probabilities within the next few decades is being made at the Jet Propulsion Laboratory, Pasadena, CA, USA, and in the University of Pisa, Italy.

We consider the establishing of the national information center responsible for collection, storage, analysis, etc. of observational data from the Russia observatories and interaction with the MPC and other world centers to be a very important task (see [4]). The international cooperation in the field should be very responsible and strictly coordinated. The Minor Planet Center is considered as the primary (the only) world (international) clearing house!

2.2. Characterization

It is highly desirable to have full information on the threatening body. This information should include a lot of important data:

- precise and regularly updated orbital parameters;
- physical and chemical (mineralogical) properties;
- expected details of entry;

The major goal of follow-up observations, discussed in the previous subsection, are both orbit redetermination and remote determination of the physical properties of the hazardous bodies.

Radar observations of the most interesting (and close) asteroids and comets are of a great value, not only because of providing very accurate information on the orbital motion of an asteroid, but also in providing data on its physical properties (shape, rotation velocity, structure and composition of surface layers, etc.). The plans for reconstruction and use of 70-m radars in Evpatoria (Ukraine) and Ussurijsk for the study of PHO is going on.

Several projects of space facilities for study (characterization) of the dangerous bodies and testing the prevention technologies are considered. The pre-phase A study of an automated mission to an asteroid is completed. The Phase A is to be completed in 2012. The major goals of the mission, preliminary named "Apophis", are to carry out a study of physical and chemical properties of an asteroid and to put a special radio beacon into circum-asteroid orbit aimed for precise determination of the asteroid's orbital parameters. The period 2018-2022 seems to be the most reasonable window for the launch. Both distant and contact (if a lander option is included) modes of study are considered. See for more details [11].

2.3. Risk assessment

Assessing the degree of threat (or risk) is a crucial component of the ACH problem, because the underassessment or over-assessment of risk leads to devastating consequences or huge material and social losses, respectively. One should distinguish an average impact risk and a specific impact risk. The average degree of threat is calculated over a large time interval and this average risk is moderate. A specific impact risk could be extremely high. Using simple words we can define risk as a product of two major factors:

$$\text{risk} = \text{probability of collision} \times \text{consequences}$$

The probability of collision typically is poorly known. One of us (B.Shustov) have compared a dozen of papers of scientists in Russia, where the probability of a collision of Apophis with our planet in 2036 is estimated on the basis of different models. The range of estimates exceeds some orders of magnitude! For making a decision procedure this dispersion seems to be not acceptable. This implies the necessity of new observations and reconciliation of numerical models of the motion of Apophis (and PHOs in general).

From the other side, to define the consequences of the specific collision is rather an uncertain procedure. The well known simplified Torino scale and the more technical Palermo scale of NEO threats were introduced to qualify the approximate level of the threat. These do not take into account many factors, e.g. details of the entry. The importance of the details is illustrated by Fig.2, adapted from [12]. The figure summarizes the results for asteroidal (left) and cometary (right) impacts. It shows what style of impact is realized at different projectile sizes and trajectory angles. The impact angle is a very important parameter. If Chelyabinsk meteoroid went into atmosphere at higher trajectory angle (i.e. steeper) the consequences would be much more serious.

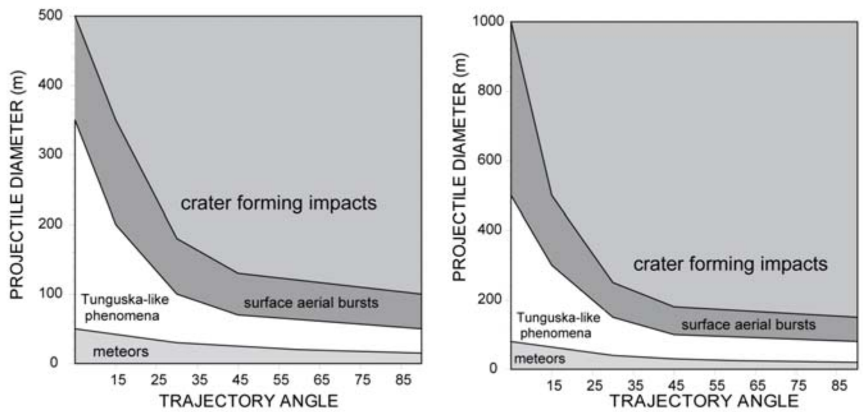

Fig. 2. Results of impacts of asteroids (left) and comets (right) depending on the projectile sizes and trajectory angles.

The next example concerns the consequences of a tsunami caused by the drop in the ocean of a body of given mass, structure, and velocity. These strongly depend on the depth of the sea, relief of the sea coast, and other physical (geographical) and social factors. To simply estimate them is not an easy task. The only guess is that the consequences may have a very devastating character. The attempt to estimate the risk sometimes resembles an attempt to solve an absolutely crazy mathematical problem – to find product **$0\times\infty$.** Nevertheless, the reliable and timely risk assessment should be a major outcome of the comprehensive ACH program.

The technologies to estimate both the collision probability and the consequences of impact are still not sufficiently developed. The concept of the national Program includes practical plans to support the R&D activities in these directions, e.g. construction of a data base of highly informative models of impact consequences (see section 3).

Another problem is to elaborate the criterion of an acceptable risk. We think that in Russian realities, the critical issue of elaboration of such a criterion must be solved jointly under the leadership of the Emergency Committee.

2.4. Preventing and mitigation

In previous subsections we have considered detection, characterization, and risk assessment issues. They are more or less similar (at least for detection and monitoring) both for NEOs and space debris. Preventing and mitigation in the cases of asteroid/comet collision and space debris are absolutely different. Currently the measures of counteracting the space threats includes some measures for space debris only. R&D activity in Russia, on the projects of preventing asteroid/comet impact, is going on at an initiative basis. Various suggestions (projects) for deflection and disintegration of hazardous bodies are considered at the Federal Nuclear Center (Snezhinsk), State Rocketry Center after Makeev, etc. Here we illustrate only two outputs of the studies.

Analysis of practical possibilities to deliver to the threatening body a dissector, explosive, or other means of deviation gave rise to the conclusion that it is not an easy task, even for the most powerful rocketry. In Fig.3, the shares of hazardous asteroids (those for which the minimal distance from the Earth does not exceed 2 000 000 km), that can be reached with different launchers with a given payload mass, are shown. The conclusion is simple: humankind is not able to prevent for sure a collision with a relatively close and large body (which require for the disruption, or for quick deviation a payload mass larger than half of ton).

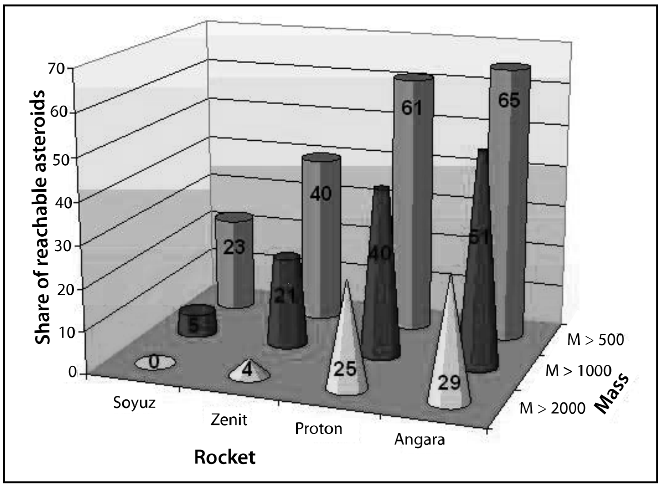

Fig. 3. The share of hazardous asteroids (minimal distance from the Earth does not exceed 2 000 000 km), which can be reached with different launchers for a given payload mass (kg).

Russia considers international collaboration in the field of preventing the collisions and/or mitigation as vitally important. One of the first steps in this direction is made by participation in the NEOShield Project initiated by the European Council. We would like to remind that all these issues are politically sensitive ones.

3. ON THE NESESSITY OF AN INTERNATIONAL DATA-BANK OF THE IMPACT CONSEQUENCES

Experts of the three institute of the RAS: Institute of Dynamics of Geospheres, Institute of Oceanology and Institute of Astronomy proposed to construct world data-bank of impact consequences. The initiative was launched at the UN NEO group AT-14 meeting in Vienna in February 2012.The data bank is considered to be similar to those elaborated and/or under creation for tsunami and climatic hazards in some developed countries.

The idea is simple. It is known that the consequences of a collision are very dependent on many details: the characteristics of the colliding body, parameters of atmospheric entry, the relief details, the density of populations, industrial environment etc. One requires a lot of CPU time at the most powerful supercomputers to calculate consequences with a sufficient accuracy. The suggestion is to pre-calculate the consequences for all the most “sensitive” (to the ACH) regions on the Earth during “quiet age” (before the next serious collision). This will speed up and facilitate decision-making process. It is clear that for some countries it will be problematic to construct an own part of the relevant data bank. A dedicated international program would be helpful.

The solution of task will require internationally approved approach and technologies. At the moment several tens of the physically important parameters of colliding body (size, mass, velocity, trajectory angle, structure, composition are the most obvious ones), a lot of data on geological, social industrial etc. characteristics of a given area and mathematical (numerical) restrictions are considered as input data. We hope this initiative will be supported by scientific community and governing bodies.

4. CONCLUSION

The conclusions are simple:

- Life will not get easier. Both the space debris problem (this will be inevitably more difficult because of the active expansion of humankind in space) and the NEO problem (this is serious by nature but still poorly recognized) should be solved.
- Russia is developing the national program of counteracting space threats.
- National programs are useful steps for joining the international cooperation.
- International Program(s) of counteracting space threats will become more and more required. IAWN is the most urgent issue.
- An initiative on a construction of data-bank of impact consequences on an international basis seems to be a a timely proposal.

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