United Nations A/AC.105/949

General Assembly

Distr.: General
18 December 2009

Original: English

Committee on the Peaceful Uses of Outer Space

Information on research in the field of near-Earth objects carried out by Member States, international organizations and other entities

Note by the Secretariat

I. Introduction

1. At its forty-sixth session, in 2009, the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space endorsed the amended multi-year workplan for the period 2009-2011 (A/AC.105/911, annex III, para. 11). In accordance with the workplan, the Subcommittee will, at its forty-seventh session, in 2010, consider reports submitted in response to the annual request for information from Member States, international organizations and other entities on their near-Earth object activities.

2. The present document contains information received from Germany, Italy, Japan, Myanmar, Poland, Spain and the United Kingdom of Great Britain and Northern Ireland and from the International Astronomical Union, the Space Generation Advisory Council and the Secure World Foundation.

II. Replies received from Member States

Germany

[Original: English]

German Aerospace Center, Institute of Planetary Research, Berlin

Scientists at the Institute of Planetary Research of the German Aerospace Center (DLR) in Berlin-Adlershof have been engaged in international research on near-Earth objects (NEOs) for many years. The work includes the planning, development and use of space missions for NEO research and observation

V.09-89272 (E) 200110 210110

campaigns for the physical characterization of NEOs using astronomical telescopes of various sizes and types. In some cases observations can be carried out remotely from DLR using facilities established by DLR staff, theoretical two-dimensional impact simulations, data reduction and analysis and the publication of results in major peer-reviewed journals and activities within the European Fireball Network.

Space missions relating to near-Earth objects

The Institute of Planetary Research has been selected to contribute the payload for the first "Kompaktsatellit" of DLR, which will consist of a series of small Earth-orbiting spacecraft. The winner of the DLR internal competition was the AsteroidFinder project, the objective of which will be to search for inner-Earth objects, using a 25-centimetre telescope with a 2 × 2 square-degree field of view and the novel Electron Multiplying Charge Coupled Device camera. The mission will be an ideal complement to ground-based NEO search programs and should become operational in 2013, extending the search into regions of the sky that are difficult to observe or unobservable from the ground. The AsteroidFinder project is expected to detect about 10 previously unknown inner-Earth objects during its operating time of one year (see http://www.dlr.de/pf/en/desktopdefault.aspx/tabid-174/319_read-18911/).

Observations have commenced in the wavelength range of 3-5 micrometres using the National Aeronautics and Space Administration (NASA) of the United States of America Spitzer Space Telescope ("warm" Spitzer-operated without cryogen). The data from those observations will be used to determine the sizes and albedos of some 700 sub-kilometre NEOs, the first major step in the physical characterization of the NEO population. DLR prepared a successful proposal, has been awarded 500 hours of observation time over the next few years and will play a key role in the analysis of the data. Thermal models developed by the Institute of Planetary Research will be used to derive sizes and albedos and, where possible, information on surface properties.

Complementary ground-based observations of near-Earth objects

A major area of activity is observational work with telescopes such as the NASA Infrared Telescope Facility on Mauna Kea in Hawaii and with optical telescopes. In cooperation with the Calar Alto Observatory in Spain, the Institute signed a contract to operate the remotely controlled 1.2-metre telescope for optical photometric and astrometric observations of NEOs for 100 nights per year for three years. The first observing run started in April 2009.

The data from such observations make it possible to determine crucial parameters such as the sizes, albedos, rotation parameters and shapes of NEOs. The interpretation of these observations requires extensive theoretical work and computer modelling of the physical characteristics of NEOs. Observations from different telescopes often complement each other. In certain cases, in which detailed information about an asteroid, such as spin vector and shape, is available from other sources, the thermal infrared data enable accurate information on size, surface roughness, thermal inertia and regolith properties to be derived.

This work is carried out in collaboration with groups in the United States (University of Arizona, Massachusetts Institute of Technology, University of

Hawaii) and in Europe (University of Belfast, University of Helsinki, Observatoire de la Côte d'Azur). Former research students of the Institute now hold positions at the Steward Observatory of the University of Arizona and at the Observatoire de la Côte d'Azur and continue to collaborate with staff of the Institute.

In addition to the above-mentioned research activities, an online database of the physical properties of all known NEOs is maintained. The database is available on the Internet (http://earn.dlr.de) and is updated on a daily basis. Since September 2009, the database has accumulated entries for more than 6,300 near-Earth asteroids derived from data on the physical properties of NEOs published in more than 700 papers. References are given to almost 1,000 relevant publications.

Theoretical studies and simulations

A theoretical study entitled "Planetary Evolution and Life", involving advanced computer modelling and simulations based on a multimaterial hydrocode, is analysing the formation of craters and the associated effects of asteroid and comet impacts on the Earth, such as the distribution of ejecta, chemical processes in the impact vapour plume and the evolution of the impact blast cloud. Specific impacts on oceans and continents can be assessed specifically using a multimaterial hydrocode. The project is part of a research alliance which started in 2007 and is scheduled to continue until 2012 and is funded by the Helmholtz Association of German Research Centres.

European Fireball Network

The Institute is involved in the operation of the European Fireball Network, a network of all-sky cameras that records the tracks of large meteoroids colliding with the Earth. The European Fireball Network provides fundamental data for the computation of the mass flux near Earth and the probability of collisions with larger bodies.

Cameras of the European Fireball Network routinely monitor the night sky over Central Europe. The network comprises 10 camera stations in the Czech Republic, 2 in Slovakia and 13 in Austria, France and Germany deployed approximately 100 kilometres apart to cover a total area of 10^6 square kilometres. In 2008, the Network detected a record total of 41 fireballs (www.dlr.de/pf/desktopdefault.aspx/tabid-623/).

Publications

Publications relating to the above-mentioned research activities are available on request. The annual reports of the Institute of Planetary Research are available on the Internet (http://www.dlr.de/pf/en/).

Italy

[Original: English]

The instruments of the Italian Space Agency play a fundamental role in the study of primitive bodies, such as comets and asteroids, on missions which are currently cruising towards their targets. In 2009, the instruments on board the Rosetta spacecraft of the European Space Agency, on its way to comet 67P/Churyumov-Gerasimenko, observed the Steins asteroid during its fly-by, which occurred on 5 September. The Osiris wide-angle camera, made in Italy, produced the first images of the NEO. In the meantime, the NASA Discovery mission Dawn continues towards Vesta and Ceres carrying the Italian Visible-IR Mapping Spectrometer.

Japan

[Original: English]

Japanese NEO activities started with the establishment of the Japan Spaceguard Association (JSGA) in 1996. JSGA constructed a 1-metre wide field telescope for NEO detection, which became operational in 2002 and which was mainly used for follow-up observations. JSGA repaired the telescope in 2006 and it is now able to detect NEOs down to a magnitude of 20.5, which is comparable to detections by the Catalina Sky Survey and the Spacewatch programme in the United States. A list of NEO follow-up observations is shown in the table below.

JSGA has carried out various educational activities over the last 10 years. For public outreach, JSGA has produced an educational package on NEO detection in English, Japanese and Spanish and published two books and a number of articles in journals and newspapers. In 2009, JSGA held spaceguard symposiums in four locations and published the second issue of its research bulletin entitled *Spaceguard Research*.

Near-Earth object observations by the Japan Spaceguard Association (as at September 2008)

	Near-Earth asteroids			*Comets*	
Year	*Number observed*	*Number of position measurements*	*Sum of position measurements*	*Number observed*	*Number of position measurements*
2000	23	205	4 240	20	113
2001	29	560	5 907	16	275
2002	24	243	2 018	13	339
2003	54	567	4 938	18	165
2004	23	233	2 908	4	20
2005	8	42	2 431	0	0
2006	25	297	3 224	5	66
2007	34	408	7 219	15	108
2008	31	162	4 534	14	110
2009	20	87	2 594	4	27
Total	**271**	**2 804**	**40 013**	**109**	**1 223**

Another important NEO activity is the Hayabusa mission to the NEO called Itokawa. The scientific purpose of the mission is to gain information on the mysteries behind the genesis of the solar system by analysing the composition of the asteroid; for this, technology to bring back samples of asteroids needs to be developed. In 2005, when the Itokawa asteroid was nearer to the Earth, many enlarged images were obtained and a trial return sample of Itokawa surface materials was taken. The return of the ongoing Hayabusa mission is scheduled for June 2010. The results of the mission are important not only for science but also for spaceguard since Itokawa is an asteroid of the type that may come close to the Earth, and the mission is the first to have studied an asteroid of this type. The Japanese Aerospace Exploration Agency is now considering another NEO sample return mission which, if successful, would provide information about another type of NEO.

Myanmar

[Original: English]

Ministry of Science and Technology

Introduction

NEOs are a matter for global concern since, rare though such occurrences are, any nation could suffer the devastating effects of an impact at any time. Therefore, alongside their focus on deriving benefits from the peaceful uses of outer space, space agencies and research institutions conduct surveys of NEOs and devise hazard mitigation strategies to protect the Earth from such potentially hazardous objects. Although Myanmar is not currently a spacefaring country, it wishes to make a contribution in proportion to its capabilities through research and development in this area.

Research and development activity on mitigation strategies for near-Earth objects

One of the main functions of the Myanmar Ministry of Science and Technology is to enhance the nation's development by carrying out various research and development activities. The Ministry has been pursuing such activities in space sciences and applications, especially in the fields of remote sensing and the Geographic Information System, satellite communications and aerospace vehicles for several years. In this context, the Ministry is to launch a research and development activity on NEOs with the following aims: to strengthen cooperation with international bodies in space science and technology; to focus on the technologies used in NEO detection, tracking and monitoring; and to contribute to information sharing on current and forthcoming activities, while aiming to foster knowledge and understanding of the NEO environment and mitigation strategies.

In order to achieve these aims, the research and development activity will comprise the following: (a) creation of a cosmic study team which will prepare reports and occasional publications; (b) study of the space environment with an emphasis on the orbital region of NEOs, later focusing more closely on potentially hazardous objects; (c) with more familiarity with the technical know-how on the matter, analysis of scientific and technical publications on NEO risk mitigation systems and methodologies; and (d) study of related subjects, such as the material properties and the density and size of NEOs for the selection of potential mitigation methods.

The research will not cover such areas as NEO search and detection as financial and technical resources are currently insufficient.

Since the 1960s, it has been known that most of the craters on the moon are not of volcanic origin but were formed by the impact of objects. The Earth could therefore be at risk as the orbits of objects such as meteoroids, asteroids and comets, which are small in mass compared to planets, could change and intersect with that of Earth, leading to a risk of collision. Such impacts are expected to occur on timescales of millions of years. Catastrophic impacts such as the Tunguska and Eastern Mediterranean events have increased awareness of the potential danger of such objects to the Earth.

A mitigation strategy might be required urgently since hazardous objects might be discovered days before they approach the Earth or the warning time before an impact might be very short. Therefore the research and development activity of the Ministry will mainly focus on mitigation systems.

The two major strategies to prevent the collision of NEOs with the Earth are fragmentation and deflection. Fragmentation could still entail the risk of a collision since the size of the fragments would be difficult to predict. On the other hand, altering the orbit of a hazardous NEO would require sufficient time. Therefore a mitigation strategy must be selected on the basis of the size, composition and orbital parameters of the object and the time available. The relative merits and drawbacks of various mechanisms for the fragmentation or deflection of potentially hazardous NEOs will be examined and the development of a mathematical model containing various components of the possible deflection or fragmentation system will be under consideration.

When selecting the mitigation strategy, it should be noted that the risk of technology being misused could be greater than the risk of an asteroid impact. In this context, sufficient preparation, efficient planning, timely decision-making and thorough research should be in place before a collision threat becomes known. Myanmar's contribution to this would be to develop a mitigation system model based on the most common characteristics of hazardous NEOs.

Conclusion

The Myanmar Ministry of Science and Technology wishes to improve its knowledge and expertise in this field. Given the infrequent occurrence of hazardous NEO events, it should have ample time to contribute to international cooperation on the problem. The Ministry also aims to support space scientists and technicians.

While realizing that its contribution cannot be on a par with that of space-faring countries, Myanmar will continue to report to the Committee on the Peaceful Uses of Outer Space on the outcomes of its research and development activity.

Poland

[Original: English]

In the field of NEOs, studies were conducted on a net-centric observation and simulation system to gather and process data obtained from NEO observations. One Polish Fireball Network is currently operating a NEO observation system.

Spain

[Original: Spanish]

The Space Situational Awareness Programme of the European Space Agency involves guaranteeing the safe operation of European space assets. This initiative includes activities such as the detection and monitoring and study of NEOs.

The numerous facilities contributed to the programme by Spain include several astronomical observatories specializing in the detection of asteroids near the Earth. Also of great importance is the Near Earth Objects Dynamic Site system centre, which carries out systematic monitoring of the risks of the collision of an asteroid with the Earth. It is also a centre for data related to NEOs, offering services to users such as the provision of orbital data on NEOs and estimates regarding the approach of such objects to the Earth and other bodies in the solar system.

United Kingdom of Great Britain and Northern Ireland

[Original: English]

The British National Space Centre (BNSC) maintains an active role in addressing the NEO problem by encouraging coordination at national, European and international levels to reach agreement on understanding of, and development of effective measures to address, the threat posed by NEOs. That leadership role is demonstrated by, among other things, the United Kingdom's Chairmanship of action team 14 and the Working Group on Near-Earth Objects of the Committee on the Peaceful Uses of Outer Space.

The United Kingdom has strong NEO research capabilities building on its astronomy, planetary science and space surveillance capabilities, which BNSC regularly calls upon for impartial technical support and advice. In 2009, United Kingdom organizations have conducted a wide range of activities, a number of which are summarized below.

Remote observation and measurement of the NEO population

A partnership of United Kingdom astronomers, from Durham University, Queen's University Belfast and the University of Edinburgh, joined a group of United States and German institutions to use an advanced new telescope, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). Equipped with the world's largest digital camera and located on the Hawaiian island of Maui, one of its primary goals is to observe and determine the characteristics of NEOs and other bodies in the solar system and beyond. Astronomers at Queen's University Belfast continue to obtain astrometry of NEOs with identified small risks of hitting the Earth in the next 100 years, with the aim of improving their orbits.

The Open University is researching light curves of slowly rotating (mostly main belt) asteroids, using data from the Super-Wide Angle Search for Planets sky cameras, and continues to publish NEO observation results (thermal modelling and infrared spectroscopy).

In situ observation and measurement of the NEO population

At the Open University, in addition to theoretical studies aimed at understanding the formation of smaller bodies in the solar system, a number of experimental programmes are also under way. Among them is the development of a penetrometry rig to simulate a high-mass, low-speed impact of a penetrometer fixed to a landing spacecraft. Penetrometers will be key to enabling in situ measurements on an NEO surface, which is likely to be delicate, to give structural and mechanical information on the body, critical for successful mitigation and negation of the body. The Open University has an interest more broadly in instrumentation for the in situ physical and geochemical investigation of NEOs and other smaller solar system bodies. That has helped the Open University to gain a lead scientific role in the "Marco Polo" NEO sample return mission proposed through the Cosmic Vision programme of the European Space Agency. In addition, research of the Open University on NEOs continues in the field of meteoritics and extraterrestrial sample analysis, using its world-class suite of geochemical laboratories, which forms part of the United Kingdom Cosmochemical Analysis Network.

Risk assessment

The Astronautics Research Group at the University of Southampton is conducting a significant amount of research into the effects of NEO impacts on the Earth. The NEO research programme at Southampton is aimed at assessing the global threat to Earth posed by small, sub-kilometre diameter NEOs. The impact-generated effects resulting from a NEO impact have an effect on the Earth's ecosystem and serious consequences for the human population. The primary challenge in the research is accounting for each impact-generated effect and developing an adequate model to simulate it. To this end the computer simulation tool under development has the capability of modelling small NEO impacts. This tool tackles the hazard on both a local and global scale, tracking the consequences of an impact on the human population. Each of the impact-generated effects will affect the human population and infrastructure to varying degrees. Therefore the analysis of mortality rates and infrastructure cost is the key feature of the simulation. Overall hazard assessment of a NEO impact event will be rated by the casualty figure and level of infrastructure damage.

Mitigation

The objective of the work conducted by the University of Glasgow is to develop fundamental optimal control theory and apply it to the interception of hazardous NEOs. Different parameters — time, mass, orbital corrections, maximum deviation etc. — will be optimized. A study of the robustness of the methods will also be performed to take into account the uncertainties on both the NEO dynamics and boundary conditions. A variety of propulsion methods, ranging from solar sails to nuclear propulsion, will be considered and the advantages and disadvantages of each assessed. Numerical simulations in a realistic scenario will be developed in order to investigate the performance of such methods and, in order to evaluate the optimal trajectories and deviation methodologies, the simulation data will be animated. This is a three-year programme funded by the Engineering and Physical Sciences Research Council.

Information dissemination

The United Kingdom continues to be home to two centres providing information on NEOs to the public and media.

The first is the Spaceguard Centre, located at the former Powys Observatory, near Knighton in mid-Wales. It represents the Spaceguard Foundation as the International Spaceguard Information Centre. It has set up the nationwide Comet and Asteroid Information Network and has a well-established outreach programme. It currently liaises with Spaceguard organizations in other countries and encourages the establishment of new ones. The Centre is also the primary Science Advisor for the Faulkes Telescope Asteroid Project and is developing a robotic NEO astrometry system (Spaceguard NEO Astrometry Project) deployed in Kenya and the United Kingdom.

The second is the United Kingdom Near Earth Object Information Centre, which was established in response to recommendations 13 and 14 of the United Kingdom Government's Task Force on Potentially Hazardous Near Earth Objects report on NEOs. The Information Centre is operated by a consortium led by the National Space Centre, under contract to BNSC. The main centre is based at the National Space Centre in Leicester, which houses a NEO exhibition and provides a primary contact point for public and media enquiries. A network of seven academic institutions active in the field of NEOs advises the Centre. These are Queen's University of Belfast, the United Kingdom Astronomy Technology Centre, the Natural History Museum, Queen Mary, University of London, Imperial College and the University of Leicester. In addition, there are three regional centres with linked exhibits and access to the Information Centre facilities. These are based in W5 in Belfast, the Natural History Museum in London and the Royal Observatory in Edinburgh. The website of the Information Centre (www.spacecentre.co.uk) provides a virtual exhibition, a resource section (for educators and the media) and the latest NEO news, including frequently asked questions. The site also allows access to the report of the United Kingdom Task Force.

Policy approach

The underlying policy approach in the United Kingdom to NEOs is recognition that the threat posed by such impactors is real, although it is a low probability occurrence, but potentially catastrophic when it occurs. It also recognizes that such objects do not respect national boundaries and the scale of their effect is such that the NEO hazard is a global issue and can only be effectively addressed through international cooperation and coordination.

III. Replies received from international organizations and other entities

International Astronomical Union[1]

[Original: English]

Near-Earth Object Program of NASA

The vast majority of NEO discoveries have been made by wide field telescopic surveys funded by NASA. The selection of competitive peer-reviewed proposals forms the basis for funding by NASA of NEO search surveys, follow-up observation programmes and efforts to provide the physical characteristics of NEOs. The NEO survey teams currently supported by NASA include the Catalina Sky Survey, the Lincoln Near-Earth Asteroid Research (LINEAR) programme of the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT) and the Spacewatch programme of the Lunar and Planetary Laboratory of the University of Arizona. Funding for the Pan-STARRS program operated by the University of Hawaii has been discontinued because the programme is not yet operational.

Brief descriptions of the three programmes are provided below:

The Catalina Sky Survey programme is currently the most productive survey for discovering NEOs. It operates three refurbished telescopes all using identical thinned, multi-channel cryogenically cooled 4K × 4K charge-coupled device (CCD) cameras:

(a) The original Catalina Sky Survey programme uses a 0.7-metre f/1.8 Schmidt telescope with a 2.9 × 2.9 degree field at the Steward Observatory Catalina Station (elevation: 2,510 m, 20 km north-east of Tucson, Arizona);

(b) The Siding Spring Survey uses the Uppsala 0.5-metre f/3.5 Schmidt telescope with a 2.0 × 2.0 degree field operated jointly with the Australian National University Research School of Astronomy and Astrophysics at Siding Spring Observatory, Australia (elevation: 1,150 m);

(c) The Mt. Lemmon Survey uses a 1.5-metre f/2.0 prime focus telescope with a 1.0 × 1.0 degree field at the Steward Observatory Mt. Lemmon station (elevation: 2,790 m), 18 km north of Tucson, Arizona. The 1.5-metre Mt. Lemmon and 1.0-meter Siding Spring telescopes are also used for astrometric follow-up and physical observations of interesting NEOs.

In cooperation with the Air Force, the Lincoln Laboratory of MIT has been operating a NEO discovery facility using 1-metre aperture Ground-based Electro-Optical Deep Space Surveillance System (GEODSS) telescopes, designed to optically observe Earth orbital spacecraft. The GEODSS instruments, used by the Lincoln Near-Earth Asteroid Research (LINEAR) programme, are located at the Lincoln Laboratory's experimental test site in Socorro, New Mexico. Tests in early

[1] The original document submitted by International Astronomical Union in English, including the images and weblinks referred to in this document, can be found on the website of the Office for Outer Space Affairs of the Secretariat (http://www.unoosa.org/).

1996 indicated that the search system had considerable promise. In the period between March and July 1997, a 1,024 × 1,024 CCD pixel detector was used in field tests and, while this detector filled only about one fifth of the telescope's field of view, four NEOs were discovered. In October 1997, a large format CCD (1,960 × 2,560 pixels) that covered the telescope's 2 square-degree field of view discovered nine new NEOs. Five more NEOs were added from November 1997 to January 1998, when both the small and large format detectors were employed. Beginning in October 1999, a second 1-metre telescope was added to the system.

Currently, the LINEAR programme telescopes observe each patch of sky five times every evening, mostly searching along the ecliptic plane where most NEOs would be expected. The sensitivity of their CCDs, and particularly their relatively rapid readout rates, allows the LINEAR programme to cover large areas of sky each night.

Since 1984, the Spacewatch system has operated a 0.9-metre aperture telescope at the Steward Observatory for discovering NEOs. First installed on the University of Arizona campus in 1923, this telescope had been moved to Kitt Peak, Arizona, in 1963. In 1982, this instrument was donated to the Spacewatch team, and in 1984 it became the first telescope to detect and discover asteroids and comets with electronic detectors (CCDs) as opposed to photographic plates or film.

The initial 320 × 512 RCA CCD detector, used from 1984 to 1988, was replaced with a large format 2,048 × 2,048 CCD detector used during the period 1989-1992. This system had a field width of 38 arc minutes and limiting magnitude of 20.5. The sensitivity of the CCD (quantum efficiency) was doubled to 70 per cent in 1992 when a thinned 2,048 × 2,048 CCD was installed and extended the limiting magnitude down to 21.0. The 0.9-metre telescope is used 23 nights per month to search for NEOs. By locking the right ascension axis in place and allowing the star fields to drift through its field of view ("drift-scan") while the CCD detector was constantly read out, this telescope scanned at a rate that covered about 200 square degrees of sky each month down to magnitude 21. Each region of sky was scanned three times, about 30 minutes apart, to examine which objects moved relative to the background stars.

The Spacewatch system was the first to discover NEOs with CCDs, a comet with a CCD and a NEO with automated image processing software. In 2001, the Spacewatch group began observing with a newly built 1.8-metre aperture telescope designed for follow-up of asteroids that get fainter after discovery. In late 2002, a large-mosaic CCD camera (four 4,608 × 2,048 CCDs) was added to the 0.9-metre aperature telescope, and the optical system was replaced to allow a wider field of view (2.9 square degrees). The 0.9-metre design now operates in the "stare" mode rather than in the previous "drift-scan" mode, whereas the 1.8-metre telescope operates in the "drift-scan" mode.

From 2005 to 2008, the Spacewatch group gradually shifted its emphasis to follow-up observations that are critical for securing accurate orbits. In addition to these activities, the Spacewatch team has been involved with studies of the Centaur and Trans-Neptunian minor planet populations and the sizes of short period comet nuclei.

The Minor Planet Center (MPC) acts as a central clearing house for astrometric and photometric data on comets, asteroids and other bodies of the solar system. Together with the co-located Central Bureau of Astronomical Telegrams, MPC also provides orbital and ephemeris information for these bodies and assigns discovery credit as well as official designations and names. For NEOs, MPC collects, organizes and verifies data, provides preliminary orbits and ephemerides, posts a list of tentative NEO objects that need confirmation via additional observations and, if appropriate, provides Earth impact predictions.

MPC is operated at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, under the auspices of Division III of the International Astronomical Union (IAU). Currently, the operations of MPC are largely funded through the Near-Earth Object Program of NASA with additional funding coming from IAU, individuals and foundations.

In addition to supporting the above-mentioned NEO search facilities, NASA also supports several observatories that provide follow-up observations for recent discoveries. Follow-up observations are required to ensure that the orbits of newly discovered objects become sufficiently accurate for the object not to be lost. These critical follow-up observatories, in addition to the work done by the Catalina Sky Survey, LINEAR and Spacewatch, include the Magdalena Ridge Observatory and the Astronomical Research Institute, both in the United States. A good number of these follow-up observations are provided by the international community of professional and amateur astronomers. These latter astronomers are amateurs in name only: many are technically sophisticated, have impressive equipment and are doing very professional work. Observational programmes to study the physical characteristics of NEOs are also funded by NASA.

Next generation near-Earth object search programmes

All the current NASA-supported telescopic NEO search facilities use telescopes that were not originally designed for the purpose. The next generation of NEO search facilities will utilize very wide field survey telescopes that are capable of seeing significantly fainter objects for a given exposure. Examples of the next generation search instruments are the Pan-STARRS and the Large Synoptic Survey Telescope.

With development funding from the United States Department of Defense, the current Pan-STARRS 1 telescope is a single 1.8-metre aperture telescope operating on Haleakala, Maui, Hawaii. The plan is to take CCD images of patches of sky (7 degrees square) twice each evening and cover the entire accessible sky three times per lunar month (28 days) using the newly developed, very large format 1.4 giga-pixel CCD camera. Hence a moving NEO will receive two observations during the first discovery evening and a set of two additional observations for another two nights within each 28-day period. Once the Pan-STARRS 4 telescope comes on line with its four 1.8-metre aperture telescopes, the system will be able to image sky fields with twice the sensitivity (penetrate 0.75 magnitude deeper into space) offered by the single-telescope Pan-STARRS 1 system, which will routinely survey to visual magnitude 23. The Pan-STARRS 1 system has been built and is expected to become fully operational in late 2010.

The Large Synoptic Survey Telescope (LSST) telescope is to be funded by the United States National Science Foundation, Department of Energy, private donors and a number of additional academic and institutional sponsors. The planned aperture of the telescope is 8.4 metres in diameter, with a field of view of 9.6 square degrees. It will be located at Cerro Pachón, in northern Chile, and if the requisite additional funding can be secured, it will be used for the first time in 2016. The observing plans are to cover the entire accessible sky every three nights down to fainter than apparent magnitude 24.

While Pan-STARRS 1, Pan-STARRS 4 and the Large Synoptic Survey Telescope will not be devoted entirely to the study of NEOs, all three programmes have included NEO discovery as a primary science goal. The product of a search telescope's field of view multiplied by the aperture area of the telescope is often used as a metric for the efficiency with which a survey can discover NEOs. This product, referred to as the "system étendu", is approximately 2 for the best performing discovery system currently in operation (the Catalina Sky Survey). The étendus for the Pan-STARRS 1, Pan-STARRS 4 and Large Synoptic Survey Telescope will be approximately 12, 51 and 319 respectively.

Interactions of the Minor Planet Center with the trajectory computation centres at the Jet Propulsion Laboratory in Pisa

While the focus of the present report is the NEO Program Office at the Jet Propulsion Laboratory, the following is a brief outline of the activities of and interactions of MPC in Cambridge, Massachusetts, and the NEO trajectory computational centres located at the Jet Propulsion Laboratory in Pisa, Italy.

Particularly for NEOs, MPC quickly provides astrometric data and preliminary orbits to both the Jet Propulsion Laboratory and the centre at Pisa. At Jet Propulsion Laboratory, once the data are received, an automatic orbit determination and future trajectory process is conducted with information on future close Earth approaches being made immediately available on the NEO website of the Jet Propulsion Laboratory. If a particularly close approach is noted as being possible by the automatic software system, the object enters the automatic Sentry system, which computes potential Earth impact probabilities and associated information such as impact time, relative velocity, impact energy and impact scale values. Sentry alerts are automatically posted on the NEO Program Office website (http://neo.jpl.nasa.gov). For objects with relatively high impact probabilities, high impact energies, and/or short intervals to the time of impact, the Sentry system will notify the NEO Program Office staff for manual verification before posting the results on the website. In such cases, the results are first checked for accuracy and then sent to Pisa for verification. At the Pisa centre, a similar process will have been under way, and if both the Sentry system and the system at Pisa yield equivalent results, the relevant information will be posted on both the Jet Propulsion Laboratory and Pisa centre websites simultaneously. Since the Sentry and the Near-Earth Objects Dynamic Site systems are completely independent, this cross-checking provides a valuable verification process before the publication of information on high interest objects for which an Earth impact cannot yet be ruled out.

Near-Earth Object Program Office of the National Aeronautics and Space Administration

In July 1998, NASA established the NEO Program Office at the Jet Propulsion Laboratory to coordinate and monitor the discovery of NEOs and their future motions, to compute close Earth approaches and, if appropriate, their Earth impact probabilities. The NEO Program Office launched a website for information on NEOs in March 1999.

The NEO Program Office receives astrometric data and preliminary orbits from MPC and then continuously improves these orbits and the resulting close Earth approach predictions as additional data are received. Once a new orbit has been successfully fitted to the available observational (astrometric) data, the object's trajectory is numerically integrated forward in time to note any close Earth approaches in the following 100 years. The Jet Propulsion Laboratory orbital computations employ state-of-the-art numerical computer models that take into account the gravitational perturbations by the planets, the Moon and large asteroids as well as relativistic and thermal re-radiation and/or outgassing (non-gravitational) effects. These updated orbits and close approach information are automatically computed and immediately posted on the NEO Program Office website. Those objects for which an Earth impact cannot yet be ruled out are automatically submitted to the Sentry system for further risk analysis.

Within the Sentry system, the possible future orbits of an object are examined and Earth impact probabilities computed for specific future dates. These results are immediately posted on the Jet Propulsion Laboratory NEO website. The only exception to this chain of events occurs if relatively large objects that have relatively high impact probabilities and/or short time intervals to possible Earth impacts are discovered by the Sentry system. In those cases, an e-mail message is sent to the NEO Program Office personnel requesting verification of the events before the information is posted on the website. This manual verification process then includes electronic correspondence with colleagues at Pisa to compare results and, if they are verified, notification of these results to NASA Headquarters. Additional verification at the Jet Propulsion Laboratory is also conducted by an independent "Monte Carlo process" that determines thousands of slightly different variant orbits that could be used to successfully fit the available observations and then numerically integrates each orbit forward to the time of the possible Earth impact. The spread of this family of trajectories at the time of the possible Earth impact gives a rigorous Earth impact probability. Because this "Monte Carlo process" requires substantial computer resources, it is used only to verify the results from the much faster Sentry system.

In addition to up-to-date information on the orbits, future close Earth approaches and Earth impact probabilities and circumstances (provided by the Sentry system), the Jet Propulsion Laboratory NEO website also provides the following information:

(a) Descriptions of NEO search programmes and links to their respective websites;

(b) Charts and statistics showing the history of NEO discoveries, which shows the dramatically increasing discovery rate since 1998;

(c) Descriptions of space missions to NEOs and links to each programme;

(d) Frequently asked questions on NEOs;

(e) Interactive orbital diagrams for all comets and asteroids;

(f) Orbital elements and absolute magnitudes (brightness estimates);

(g) Recent NASA reports relating to NEOs;

(h) Reports on recent studies done by the Jet Propulsion Laboratory NEO Program Office team, such as on the utility of gravity tractors for deflecting an Earth-threatening NEO;

(i) Recent news articles posted to the NEO website;

(j) Time-ordered tables (ephemerides), which are used by astronomers to determine the celestial positions, velocities, solar and Earth distances, apparent brightness and more than 100 other categories of information for any particular object. The award-winning, online Horizons system of the Jet Propulsion Laboratory is also used by the international scientific community to generate accurate ephemeris information for the 450,000 currently known objects in the solar system. These objects include the Sun, the planets and their moons, asteroids, comets and many spacecraft. The system is widely used by observers, researchers and mission planners to plan observations and track the targets of space- and ground-based telescopes, as well as spacecraft. Since its inception in October 1996, the Horizons system has responded to more than 10 million requests (on average, more than 2,200 per day) received from 300,000 unique locations.

Some of the most recent achievements of the NEO Program Office include:

(a) Discovery of a new asteroid designated 2009 VA, only about 7 metres in diameter, which passed within about 2 Earth radii (14,000 km) of the Earth's surface on 6 November 2009 at around 1630 EST. This is the third-closest known (non-impacting) Earth approach on record for a catalogued asteroid;

(b) Recalculation of the path of the NEO Apophis by Program Office personnel, using updated astrometric observations and improving the accuracy of existing observations. According to the recalculation, the probability of a hazardous encounter with Earth in 2036 has been significantly reduced from 1 in 45,000 to 1 in 250,000;

(c) Completion by Program Office personnel of two studies on the mitigation of Earth-threatening NEOs. These studies report on the viability of using a gravity tractor to deflect a small asteroid and on the dynamical "keyholes" during a close Earth approach that allow an impact during a subsequent Earth encounter. Gravity tractors are most effective when they can take advantage of the leverage provided by a dynamical keyhole;

(d) The rapid and successful prediction of the small (a few metres in diameter) Earth-impacting asteroid 2008 TC3 on 6 October 2008 over northern Sudan at 0246 UT and the successful recovery of meteorites from that encounter.

The development of the automatic software system already in place at the NEO Program Office took into account the next generation of search, when the discovery rate is expected to increase by more than an order of magnitude. When this occurs, the additional load will be handled by additional computers running in parallel. No significant software changes should be required. The next generation of search will probably discover 40 times the current level of Earth impact warnings (mostly cases where an imprecise initial orbit does not yet rule out an Earth impact). While some processes and interfaces will need to be refined, the NEO Program Office at the Jet Propulsion Laboratory is well positioned to handle the increased activity.

The mitigation of a threatening near-Earth asteroid

Although Hollywood has created some colourful methods for stopping an asteroid that is on a collision path with Earth, this task has never been assigned to any national or international agency, nor has such an asteroid been discovered. There have however been a number of academic and technical studies on how a devastating asteroid impact might be avoided. The main nearer-term threat is posed by asteroids since these outnumber comets by 100 to 1 in the inner solar system.

The wide range of possible sizes, trajectories and warning times for Earth-threatening asteroids means that the level of challenge to find an appropriate response will vary accordingly. Unless there are a few decades of warning time, the deflection or fragmentation of hazardous asteroids larger than a few hundred metres in diameter would require high levels of energy, possibly from nuclear explosions.

For the far more numerous asteroids smaller than a few hundred metres in diameter, with an adequate warning of several years to a decade, a weighted robotic spacecraft could be targeted to collide with the object, modifying its velocity to nudge the trajectory sufficiently to prevent an Earth impact. The spacecraft navigation technology for impacting a small body was successfully demonstrated when the Deep Impact spacecraft purposely rammed the comet Tempel 1 on 4 July 2005 in order to study its composition.

Nuclear explosions and spacecraft impacts for deflecting Earth-threatening objects have been studied in some detail. More recently, another option has been suggested for the small subset of asteroids that might pass close to the Earth a few years prior to their predicted impact, a close encounter affecting the asteroid’s motion so strongly that a relatively tiny change in its velocity prior to the close approach would be multiplied several-fold during the fly-by, thus causing the asteroid to miss the Earth on the next pass. In these relatively infrequent cases, even the very modest gravitational attraction between the asteroid and a nearby “micro-thrusting” spacecraft (nicknamed a “gravity tractor”) could provide a sufficient change in the asteroid’s velocity to prevent an Earth collision.

Successful mitigation requires that a threatening asteroid be discovered and physically characterized early enough to allow the appropriate response to be made, and the current NASA NEO Program is operated with this in mind. Since there are proportionally more smaller NEOs, however, the greatest threat of impact is posed by the relatively small objects that are most difficult to detect in advance. As a result, consideration must also be given to issuing notifications and evacuating those regions on Earth that would be affected by the imminent collision of a small, recently discovered impactor. However, if the object could be found in time and successfully deflected from the Earth-threatening trajectory using space technology, that would be a tremendous demonstration of our space-faring capabilities.

Space Generation Advisory Council

[Original: English]

As a member of the Action Team on Near-Earth Objects, the Space Generation Advisory Council (SGAC) recognizes the importance of the work of the Working Group on Near-Earth Objects and strongly supports its efforts. As outlined in the workplan of the Working Group for 2009, the International Year of Astronomy can act as a framework for raising awareness of the NEO threat. Understanding that youth needs to be made aware, SGAC works on outreach programmes to increase their involvement.

The Move an Asteroid competition, held annually by SGAC since 2008, requires students and young professionals to send in novel proposals on how to deflect an asteroid. The entries are reviewed by experts and the winner of the competition has the opportunity to present his or her paper at the SGAC annual congress, the Space Generation Congress, held in conjunction with the International Astronautical Congress (IAC). Through this competition, youth participate proactively in NEO activities and analyse the related issues.

SGAC was an official co-sponsor of the 1st IAA Planetary Defense Conference: Protecting Earth from Asteroids held in Granada, Spain, in April 2009, and two SGAC members were on the organizing committee. SGAC took the opportunity to announce the Move an Asteroid competition for 2009 as well as to interview experts about their views on several important mitigation topics, including political policy, public awareness and the use of nuclear devices. The footage was used to create a documentary aimed at the general public to inform them accurately about the dangers and future uses of NEOs, which can be found on the SGAC website.

SGAC members delivered presentations about the Council's NEO activities at the NEO Conference held in Nebraska, United States, in April and the International Astronautical Congress held in Daejeon, Republic of Korea, in October 2009.

SGAC intends to continue raising awareness and involving youth in the NEO field as well as to inform youth about current issues such as the work of the Action Team. SGAC is convinced that an informed public and, specifically, youth, can have a positive impact on the mitigation of the challenges presented by NEOs.

Secure World Foundation

[Original: English]

In 2009, the Secure World Foundation became an active member of the Action Team on Near-Earth Objects. In order to support the NEO effort, the Foundation co-organized a workshop on NEO governance focusing on international law and policy together with the University of Nebraska Space and Telecommunication Law Program in Lincoln, Nebraska, United States. A week later, the Foundation presented the findings of that workshop at the 1st IAA Planetary Defense Conference: Protecting Earth from Asteroids, and sponsored a session on the international aspects of NEO governance.

In 2009, the Foundation gave a grant to the University of Nebraska for research into legal issues related to NEOs, helped to publish a special NEO issue of *The Planetary Report* with the Planetary Society (forthcoming in 2010), submitted articles for publication in space and education journals, and assisted author Mike Moore with a book he is working on about protecting the Earth.

The Secure World Foundation is planning the following planetary defence activities in 2010: an information analysis and warning network workshop and preparation of a NEO primer with Wiki for journalists, congressional staff and diplomats.