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Paris, 29 October 2008

To: Dr. Niklas Hedman, Chief
Committee Services and Research Section
United Nations Office for Outer Space Affairs
United Nations Office at Vienna,
Wagramerstrasse 5
A-1400 VIENNA
Austria

your reference: OOSA/2008/06, CU 2008/91 (B)

Dear Dr. Niklas Hedman,

In response to your request of 7 August 2008 to the IAU to submit information on its Near-Earth Object activities for consideration by the Science Technical subcommittee of the UN committee for the Peaceful uses of Outer space (UN-COPUOS) in its forthcoming meeting, February 2009, please accept the report given below.

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I . The Minor Planet Center

by

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The Minor Planet Center (MPC) is operated at the Smithsonian Astrophysical Observatory (SAO) in Cambridge (MA, USA), and supported by the IAU. The MPC is responsible for collection, validation, and distribution of all positional measurements made world wide of minor planets, comets and outer irregular natural satellites. While the MPC handles data on all classes of object it focuses on the rapid collection and distribution of observations and orbits of Near-Earth Objects (NEOs).

The MPC's pipeline for processing NEO data is as follows:

NEO data from observers worldwide is sent to the MPC either via e-mail or via ftp. Through a sophisticated pipeline of programs and checking mechanisms, the MPC automatically identifies each object as either known, or unconfirmed and in need of further observations. One piece of software calculates the probability that each new object is a new undiscovered NEO. If this probability is > 50%, the object is placed on a web page, The NEO Confirmation Page (NEOCP), that allows users worldwide to compute the predicted position of the object to allow for additional positional measures and further orbit refinement. As these measures are secured, further observations are e-mailed to the MPC allowing better orbital calculations. Note at all times these observations and orbits are publicly available, thus allowing anyone, worldwide, to determine the status of a potential new NEO.

Once the orbit for the new NEO is determined well enough for reasonable predictions in the future, the MPC issues an announcement in the form of a Minor Planet Electronic Circular, or MPEC. These MPECs are placed on the web, and also mailed to subscribers, several times a day. These constitute the formal announcement of the NEO to the public, including using the objects provisional designation, such that the object can be addressed appropriately.

As NEOs are posted on the NEOCP, their orbits are checked for possible impacts with the Earth in the next 10 days. While these cases are extremely rare, a recent small object, 2008 TC3, was discovered that impacted the Earth the next day. It should be noted that the MPC's software accepted the incoming e-mail, posted the object on the NEOCP, secured additional follow-up observations, predicted the impact, and alerted the MPC staff. In this case the system worked nearly flawlessly, and the object was announced to the public as an impactor several hours before it burned up harmlessly in the atmosphere.

Longer-term impact predictions are undertaken by NASA's Jet Propulsion Laboratory (JPL), led by Steve Chesley, or the University of Pisa's team, led by Andrea Milani. These calculations are started following the release of MPECs containing the discovery observations of NEOs.

The MPC distributes all observations of NEOs collected in the previous day on an MPEC that is released at around 2 AM Eastern Time (Standard or Daylight). Thus, the NEO orbit and observing community is aware of all current information on all NEOs on a daily basis.

In addition to collecting and distributing observations and orbits, MPC staff facilitate cooperation among the world's cadre of follow-up observers by maintaining the NEOCP, other follow-up pages, and frequent e-mails with observers. MPC staff serve on various

IAU, NASA and US Congress panels and committees, as necessary, to assist in advancing NEO science.

[TBS, 17 October 2008]

II. NASA's Near-Earth Object Observation Program

by

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II.1. Introduction

At 6:39 GMT on the morning of October 6, 2008, Richard Kowalski discovered a near-Earth asteroid using the Mt. Lemmon 1.5 meter aperture telescope near Tucson Arizona. When these initial discovery observations were reported to the Minor Planet Center (MPC) in Cambridge (MA, USA), a preliminary orbit immediately suggested that this object was headed for an Earth impact within 21 hours. The MPC quickly made the discovery, and subsequent 'follow-up', observations available. The MPC also notified NASA Headquarters of the impending impact so that subsequent US government interagency alerts and inter-governmental notifications could begin. By the time this object entered the Earth's shadow 19 hours after discovery, some 570 astrometric (positional) observations of this object (now designated as 2008 TC3) were reported from 26 international observatories, both professional and amateur. The orbital computation centers at JPL and Pisa continuously improved the orbit for 2008 TC3 as more and more data arrived from the MPC and each center verified the results of the other. Within an hour of receiving the initial data set, JPL had predicted that the object would strike the Earth's atmosphere (at the 50 km altitude level) above northern Sudan at 02:46 GMT on October 7. Impact prediction updates were forwarded to NASA Headquarters. The final orbit 14, computed before impact, refined the impact time to 02:45:44. The time and place of the predicted impact agreed very well with a number of atmospheric entry observations including those from an unnamed U.S. satellite, infrasound signals from two ground stations, images from the Meteosat 8 weather satellite and a sighting by a KLM airline pilot flying over Chad. From the observed brightness of the object and an assumed typical reflectivity, the size of the NEA was estimated to be 2-5 meters in diameter. The impact detections suggested an explosion at an altitude of 37 km that had an equivalent energy of about one kiloton of TNT explosives. <neo.jpl.nasa.gov/news/news160.html>

This dramatic prediction of an actual impact underscored the success of the current Near-Earth Object (NEO) discovery and orbit prediction process. The discovery was made, observations were provided by 26 international observatories, the orbit and impact computations were determined, verified and announced well before the impact, which took place only 20.5 hours after the discovery itself. While improvements to the impact prediction process still need to be made, the system worked well for the first predicted impact by a near-Earth object.

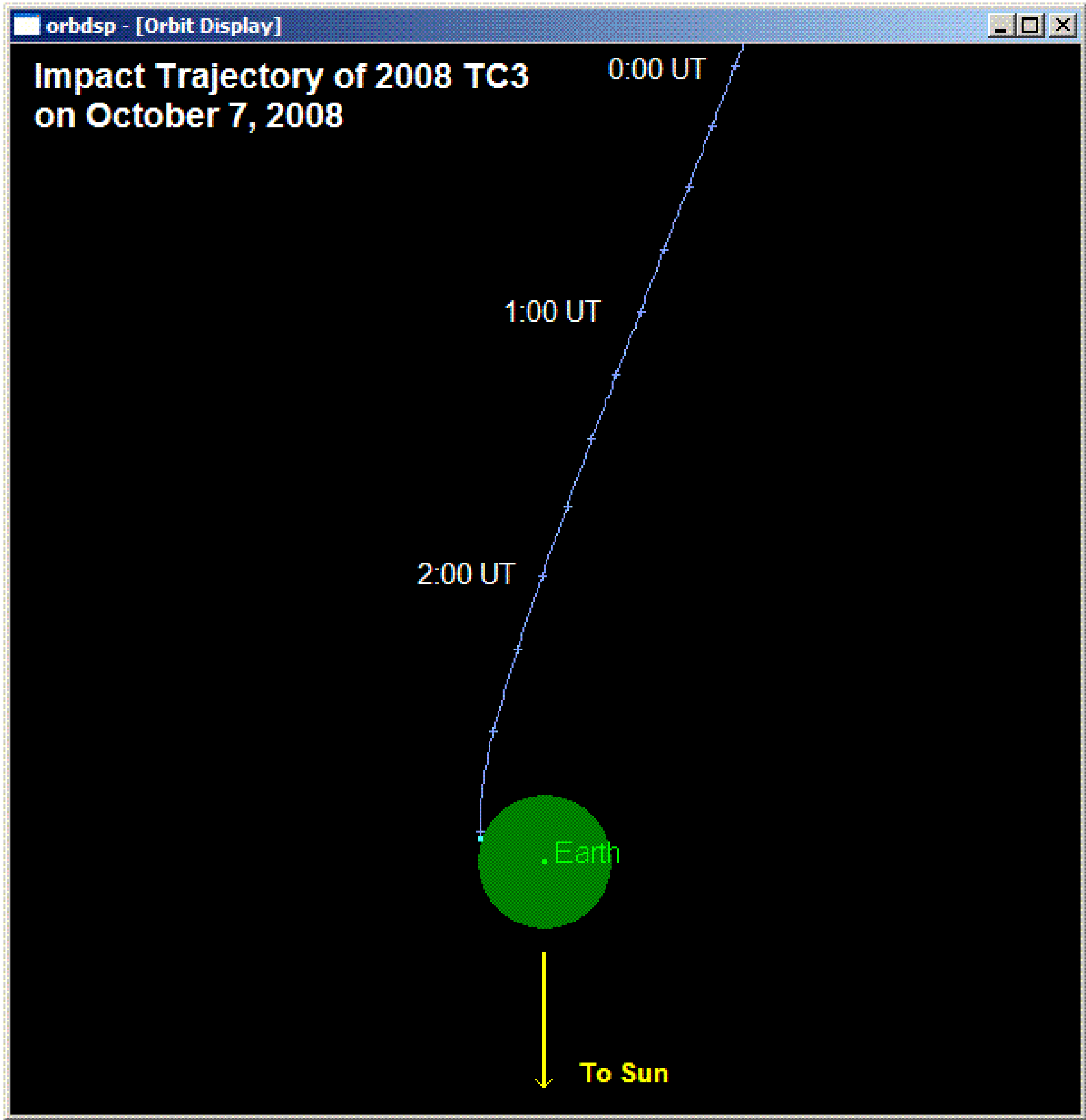

Figure 1. The terminal trajectory for Earth impacting asteroid 2008 TC3
Credit: Paul Chodas, JPL

II.2. NASA's Near-Earth Object Observations Program

Although a wide variety of excellent NEO observations and computational activities are carried out within the international community, this report will focus upon the activities of NASA's NEO Observation program and in particular, NASA's NEO Program Office at JPL.

The vast majority of NEO discoveries have been made by wide field telescopic surveys funded by NASA. This Near-Earth Object Observations program is under the direction of Lindley Johnson of the Science Mission Directorate at NASA Headquarters. The selection of competitive peer-reviewed proposals forms the basis for NASA's funding of NEO search surveys, follow-up observation programs and efforts to provide the physical characteristics of NEOs. Currently the NEO survey teams, supported by NASA, include the Catalina Sky Survey (Ed Beshore, Principal Investigator), The MIT Lincoln Laboratory LINEAR program (Grant Stokes, PI), the Spacewatch program (Robert McMillan, PI) and the PanSTARRS program operated by the University of Hawaii (Nick Kaiser, PI).

Brief descriptions of these four programs are provided below:

Catalina Sky Survey (CSS)
The CSS program currently operates two telescopes near Tucson Arizona; there is the 0.74 meter aperture telescope on Mt. Bigelow and a 1.5 meter aperture telescope operated on nearby Mt. Lemmon. The CSS also runs a 0.5 meter telescope at Siding Spring Australia. The CSS program is currently the most productive survey for discovering NEOs. <www.lpl.arizona.edu/css/>

LINEAR (Lincoln Near-Earth Asteroid Research)
Operating near Socorro, New Mexico, the LINEAR survey observes with two, co-located one meter aperture telescopes using fast readout CCD imaging devices. Until a few years ago, LINEAR was responsible for the vast majority of NEO discoveries, and it is now second only to the Catalina Sky Survey. <www.ll.mit.edu/mission/space/linear/>

Spacewatch
The Spacewatch system operates a 0.9 meter aperture telescope (Steward Observatory) for discovering NEAs and a second 1.8 meter aperture telescope that is primarily used to "follow up" discoveries made by their 0.9 meter telescope or discoveries made by other observatories. Spacewatch has one of the most successful programs for making these follow-up observations, a function that is critically important for securing the orbits of NEOs. <http://spacewatch.lpl.arizona.edu/>

PanSTARRS (University of Hawaii)
Currently, the PanSTARRS program is establishing a 1.8 meter aperture telescope on Mt. Haleakala on the Hawaiian island of Maui. This very wide field telescope is the first of the search telescopes to be specifically designed to provide wide field coverage (7 square degrees) of the entire accessible night sky on a monthly basis and should, when

operational in late 2008, become the premier instrument for NEO discoveries. There are follow-on plans for building four co-located, 1.8 meter telescopes (acting in unison) on the large island of Hawaii atop of Mauna Kea. [http://pan-starrs.ifa.hawaii.edu/public/]

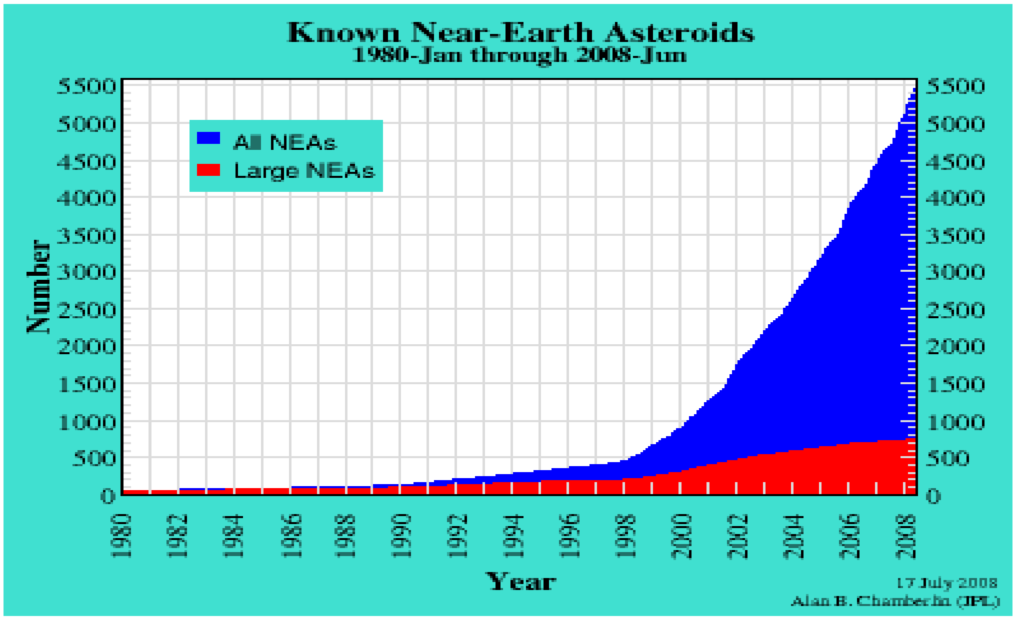

Figure 2. The discoveries of NEOs as a function of time. The blue area shows all near-Earth asteroids while the red area shows only large near-Earth asteroids (those with diameters roughly one kilometer and larger). Courtesy Alan Chamberlin, JPL

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 accurate enough that the object will not become lost. These critical follow-up observatories, in addition to the work done by CSS and Spacewatch, include the Magdalena Ridge Observatory in New Mexico and the Astronomical Research Institute directed by Robert Holmes near Charleston, Illinois. 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 of them are technically sophisticated, have impressive equipment and are doing very professional work. Observational programs to study the physical characteristics of NEOs are also funded by NASA but these efforts are outside the scope of this report.

II.3. The Next Generation of NEO Search Programs

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 previously noted PanSTARRS and the Large Aperture Synoptic Survey Telescope (LSST).

PanSTARRS (Panoramic Survey Telescope and Rapid Response System)

With development funding from the U.S. Department of Defense, the current PanSTARRS 1 telescope is a single 1.8 meter aperture telescope (PS1) 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 their 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 PanSTARRS 4 telescope (PS4) comes on line with its four 1.8 meter aperture telescopes, the system will be able to image sky fields with twice the sensitivity (penetrate 0.75 magnitudes deeper into space) than the single-telescope PanSTARRS 1 system, which will routinely survey to visual magnitude 23. Currently, the PS1 system has been built and is expected to become fully operational in late 2008.

LSST (Large Synoptic Survey Telescope)

The LSST telescope is to be funded by the U.S. National Science Foundation, the U.S. Department of Energy, private donors, and a number of additional academic and institutional sponsors. Directed by Tony Tyson (University of California at Davis), the planned aperture is 8.4 meters in diameter with a field of view of 9.6 square degrees. It will be located at Cerro Pachon, in northern Chile, and if the requisite additional funding can be secured, it is planned for first light in 2016. The observing plans are to cover the entire accessible sky every three nights down to fainter than apparent magnitude 24. <http://www.lsst.org/lsst_home.shtml>

While neither PanSTARRS 1, PanSTARRS 4 nor LSST will be devoted entirely to the study of NEOs, all of these programs 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 (CSS). The étendu for PS1, PS4 and LSST will be approximately 12, 51, and 319 respectively.

II.4. Interactions of the Minor Planet Center and the JPL and Pisa Trajectory Computational Centers

While the focus of this report will be on the NEO Program Office at JPL, the following is a brief outline of the activities and interactions between the Minor Planet Center (MPC) in Cambridge (MA, USA) and the NEO trajectory computational centers located at JPL and at Pisa Italy. At the MPC, Timothy B. Spahr is the current director and he is supported by Gareth V. Williams and Brian G. Marsden. At Pisa, Andrea Milani is in charge and is aided by Giovanni Gronchi, Fabrizio Bernardi and Genny Sansaturio at the University of Valladolid Spain. Donald K. Yeomans is the manager of NASA's NEO Program Office at JPL with key personnel including Steven R. Chesley, Alan Chamberlin, Paul W. Chodas and Jon Giorgini.

The MPC is the international clearinghouse for astrometric data of near-Earth objects and other solar system bodies. The MPC, whose role is authorized by the International Astronomical Union (IAU), collects these data, designates and verifies them, provides object designations and discovery credits, and makes the data available to the public, including the trajectory computation centers at JPL and Pisa. The MPC has many additional responsibilities including generation of preliminary orbits for NEOs, web-based notification of potential new NEO discoveries to follow-up observers, and generation of ephemeris information that enables these follow-up observations.

Particularly for NEOs, the MPC quickly provides astrometric data and preliminary orbits to both JPL and Pisa. At JPL, 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 JPL NEO web site. If a particularly close approach is noted as being possible by the automatic software system, the object enters the automatic SENTRY system that computes potential Earth impact probabilities and associated information such as impact time, relative velocity, impact energy, impact scale values, etc. SENTRY alerts are automatically posted to the NEO Program Office web site <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 Office staff for manual verification before posting of results to the web. In these latter cases, the results are first checked for accuracy and then sent to Pisa for verification. At Pisa, a similar process has been underway and if both the SENTRY system and Pisa's NEODyS systems yield equivalent results, the relevant information is posted to both the JPL and Pisa web sites nearly simultaneously. Since the SENTRY and NEODyS system 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.

II.5. NASA's Near-Earth Object Program Office

In July 1998, NASA established a NEO Program Office at JPL to coordinate and monitor the discovery of NEOs and their future motions, to compute close Earth approaches and, if appropriate, their Earth impact probabilities. In March of the following year, JPL's NEO Program Office posted its web site for information on near-Earth objects (e.g., upcoming close approaches, ephemeris information, and orbital data). <neo.jpl.nasa.gov>

JPL's NEO Program Office receives astrometric data and preliminary orbits from the 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 next 100 years. The JPL orbital computations employ state-of-the-art numerical computer models that take into account the gravitational perturbations by the planets, the moon, large asteroids, as well as relativistic and thermal re-radiation and/or outgasing (non-gravitational) effects. These updated orbits and close approach information are automatically computed and immediately posted to the NEO Program Office web site. Those objects for which an Earth impact cannot yet be ruled out are automatically submitted to the SENTRY system for further risk analysis.

Within SENTRY, the possible future orbits of an object are examined and Earth impact probabilities computed for specific future dates. These results are immediately posted to the JPL NEO web site. 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 this latter scenario, an email message is sent to the NEO Program Office personnel requesting verification of the events before the information is posted to the web site. This manual verification process then includes electronic correspondence with colleagues at Pisa Italy to compare results and, if verified, notification of these results to NASA Headquarters. Additional verification at JPL 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 Earth close approaches, and Earth impact probabilities and circumstances (SENTRY), the JPL NEO web site also provides the following information:

- Descriptions of NEO search programs and links to their respective web sites
- Charts and statistics showing the time history of NEO discoveries, which shows the dramatic increasing discovery rate since 1998
- Descriptions of space missions to near-Earth objects and links to each program
- Frequently asked questions for near-Earth objects
- Interactive orbital diagrams for all comets and asteroids
- Orbital elements and absolute magnitudes (brightness estimates)
- Recent NASA reports relating to NEOs [http://neo.jpl.nasa.gov/links/]
- Reports on recent studies done by the JPL NEO Program Office team, such as on the utility of gravity tractors for deflecting an Earth threatening NEO. <neo.jpl.nasa.gov/neo/b612_report.html>
- Recent news articles posted to the NEO website <http://neo.jpl.nasa.gov/news/>
- Time-ordered tables (ephemerides) that are used by astronomers to determine any object's celestial positions, velocities, solar and Earth distances, apparent brightnesses, and more than 100 other categories of information for any particular object. This award-winning, on-line Horizons system 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, planets, their moons, asteroids, comets, and many spacecraft. This 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 ten million requests (on average, more than 2200 per day) received from 300,000 unique locations.

- A comprehensive report on the future motion of near-Earth object Apophis – an object that will pass within 5 Earth radii of the Earth's surface (below the distance of communications satellites) on April 13, 2029 and currently has a 1 in 45,000 chance of impacting Earth seven years later, on April 13, 2036. <http://neo.jpl.nasa.gov/apophis/>

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

- The rapid and successful prediction of the small (few meter-sized) Earth impacting asteroid 2008 TC3 on October 6, 2008 at 02:46 UT over northern Sudan <neo.jpl.nasa.gov/news/news160.html>
- The successful prediction of an Earth close approach to within 1.4 lunar distances (554,200 km) by the near-Earth object 2007 TU24 on 2008 January 29 – an object whose diameter is approximately 330 meters.
- The successful prediction of a Mars close approach to within 26,000 km by the near-Earth asteroid 2007 WD5 on 2008 January 30 – an object whose diameter is approximately 50 meters.
- NEO Program Office personnel have established excellent interfaces with the next generation NEO survey teams (i.e., PanSTARRS, LSST).

The automatic software system already in place at JPL's Near-Earth Object Program Office has been developed with an eye toward 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 with additional computers running in parallel. No significant software changes should be required. The next generation of search will likely 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 JPL is well positioned to handle the increased activity.

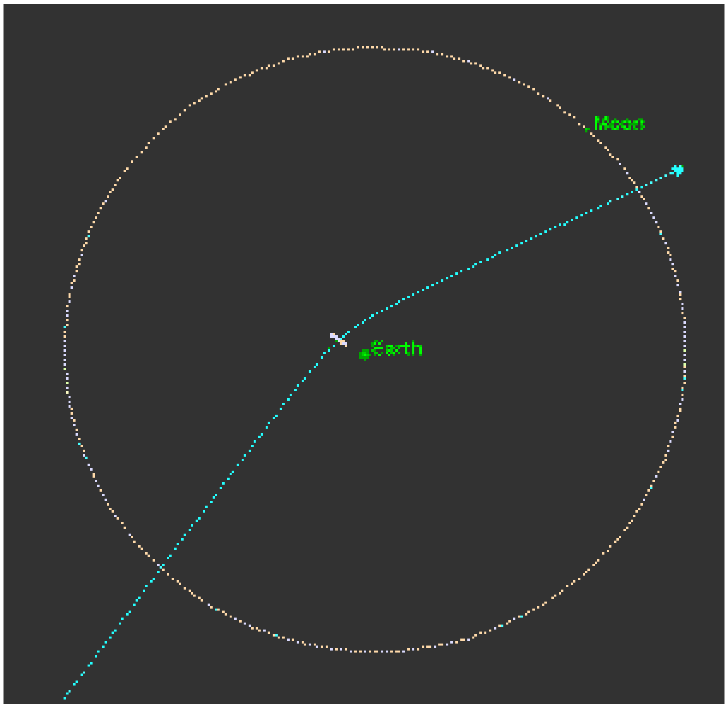

Figure 3. The passage of asteroid Apophis by the Earth in 2029 alters its subsequent trajectory and causes its position uncertainty region to expand rapidly as it moves away from Earth. As a result, the asteroid's motion is much less predictable after the 2029 close Earth approach. Even so, the asteroid's uncertainty region is not large enough to extend to the moon as it passes by, and so neither an Earth of lunar impact is possible in 2029.

[DKY, 23 October 2008]

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Yours sincerely,

Karel A. van der Hucht