

TESTIMONY BEFORE THE HOUSE COMMITTEE ON SCIENCE AND  
TECHNOLOGY  
SUBCOMMITTEE ON SPACE AND AERONAUTICS

NEAR-EARTH OBJECTS (NEOs) – STATUS OF THE SURVEY PROGRAM AND  
REVIEW OF NASA’S REPORT TO CONGRESS

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Mr. Chairman and members of the Subcommittee, thank you for the opportunity to appear today to discuss the potential threats of near-Earth objects (NEOs), our progress toward meeting the discovery goal articulated in the NASA Authorization Act of 2005, the role of the Arecibo planetary radar within the NEO program and the response options available if a NEO is found to be on an Earth impacting trajectory.

**The Near-Earth Object Population:** When the Earth was young, frequent collisions of comets and asteroids likely delivered much of the water and carbon-based molecules that allowed life to form, and once life did form, subsequent collisions may have punctuated the evolutionary process and allowed only the most adaptable species to progress further. We may owe our very existence atop the world’s food chain to these objects. As the Earth’s closest neighbors (some pass within the moon’s distance), these icy comets and rocky asteroids have been termed near-Earth objects. Their proximity to Earth presents an opportunity to utilize their vast metal, mineral and water ice resources for future space structures and habitats. Their water resources can be broken down into hydrogen and oxygen – the most efficient form of rocket fuel. These near-Earth objects may one day be the resources, fueling stations and watering holes for human interplanetary exploration. While these objects are of extraordinary scientific interest, likely enabled the origin of life itself, and may loom large for the future development of space exploration, their proximity to Earth also presents a potential horrific threat should a relatively large near-Earth object once again strike Earth without warning.

**Potentially Hazardous Asteroids:** Near-Earth objects are comets and asteroids that can pass within 45 million kilometers of the Earth’s orbit. While some showy, naked-eye comets may occasionally pass close to Earth, it is the difficult to find (but far more numerous asteroids) that are of most concern in near-Earth space today. About one fifth of the near-Earth asteroids can approach the Earth’s orbit even closer (to within 7.5 million kilometers), and these so-called potentially hazardous asteroids (PHAs) are of most concern for near-term hazard avoidance.

Celestial debris hits the Earth all the time, but the vast majority of it is so small that it does not survive passage through the Earth’s atmosphere. The debris is created over

millions of years, as asteroids inevitably run into each other, producing smaller fragments, which themselves collide yielding even more debris. Over time, the fragments and debris spread out, and some of it migrates into Earth approaching orbits. The Earth is pummeled with more than 100 tons of impacting material each day but almost all of it is far too small to cause anything other than a harmless meteor, or shooting star, or the occasional fireball event. Larger objects are less numerous than smaller objects and hit the Earth less often. While a basketball-sized object strikes the Earth's atmosphere daily, larger car-sized impactors hit only a few times each year, and even these generally break up into smaller pieces as they streak through the atmosphere. Occasionally a fragment of a larger impactor will reach the Earth's surface -- one such hit may have occurred less than two months ago when a reported asteroid fragment perhaps one meter in diameter struck in southern Peru creating a 13-meter crater near Lake Titicaca.

Larger impactors with diameters in the 50 to 140 meter range, while they do not usually impact the ground, can result in damaging air blasts that cause significant destruction. For example, on June 30, 1908, an impactor with a diameter of about 50 meters detonated over the Tunguska region of Siberia and leveled trees for 2000 square kilometers. Its impact energy has been estimated at about 10 million tons of TNT explosives (10 megatons or 10 MT), comparable in energy with a modern nuclear weapon. Roughly speaking, PHAs that have diameters larger than 140 m can punch through the Earth's atmosphere and cause regional damage if they strike land or create a harmful tsunami should they impact into an ocean. There are thought to be about 20,000 PHAs in this size range, each with a potential impact energy of 100 MT or more. On average, one of these objects would be expected to strike Earth every 5000 years and therefore would have a 1% probability of impact in the next 50 years. Although their mean impact frequency would be about once every 500,000 years, PHAs larger than a kilometer in diameter could cause global consequences due to not only the extraordinary blast itself (50,000 MT) but also the dust and debris thrown into the air, and the subsequent firestorms and acid rain. The extinction of the dinosaurs and a sizable fraction of the Earth's other species some 65 million years ago is thought to be due to an impactor with a diameter of about 10 kilometers that created an impact energy of as much as 50 million MT. Over very long time intervals, PHAs with diameters greater than one kilometer are statistically the most dangerous objects because their impacts would cause global consequences.

**NASA Responses to the PHA Issues:** In 1998, before the Subcommittee on Space and Aeronautics, a NASA representative outlined the goal to discover and catalog 90% of the NEOs larger than one kilometer by the end of 2008. There are currently thought to be over 900 of these objects, and about 80% of them have already been found and cataloged. Roughly the same percentage of PHAs in this size range has also been found. When this goal has been reached, 90% of the global risk from PHAs would be retired. Almost all of these discoveries have come by way of NASA supported search programs.

As part of the NASA Authorization Act of 2005, NASA was asked to consider options for extending the search down to objects as small as 140 meters in diameter, and to find and catalog them within 15 years of the Act becoming law (i.e., by the end of 2020). By

finding and cataloging 90% of this population of PHAs, the statistical or actuarial risk to Earth from PHAs of all sizes would be reduced by 99% from pre-survey levels. We can speak of risk reduction in this case because once an object is discovered and cataloged, its future motion can accurately be predicted and, in the unlikely case where it does threaten Earth, there would be sufficient time to deflect it, thus saving the enormous costs due to fatalities and/or infrastructure damage. According to a 2003 NASA NEO Science Definition Team study that undertook a cost/benefit analysis for the discovery of PHAs, the risk reduction accruing from this next generation PHA search would pay for itself in the first year of operations. While an impact by a 140 meter-sized object would not generate global physical consequences, its impact energy would still be about 100 MT, and the likelihood of one of these impacts is 100 times greater than an impact by one of the less numerous one kilometer-sized PHAs.

With regard to the uncertainty associated with threats from PHAs, the largest factor, by far, is the large number of undiscovered objects in the size ranges that are small enough to be very numerous but large enough to easily penetrate the Earth's atmosphere. For example, we have discovered only about 4% of the 20,000 PHAs larger than 140 meters and less than 1% of the 200,000 objects larger than 50 meters. The solution to this uncertainty is to continue and hopefully accelerate the search for PHAs. Once we find the vast majority of them, they can be tracked, cataloged and then ruled out (or in) as threats during the next 100 years or so. This process can continue year after year so the window of safety is always at least 100 years. There are other, less significant, uncertainties dealing with the refinement of a particular object's size, mass and structure as well as the dynamical model that is used to accurately predict the object's motion over 100 year time scales. For example, over long time intervals, the minute pressure of sunlight and its thermal re-radiation can significantly affect a PHA's motion. For a select number of Earth approaching objects, we will need the use of the planetary radars, or possibly rendezvous spacecraft missions, to better understand their sizes, shapes, masses, surface properties, and possible binary natures.

**The Next Generation of Search:** As noted, the current NASA NEO goal is focused upon the discovery and tracking of objects one kilometer in diameter and larger. It is not realistic to expect the current survey program, with its modestly sized telescopes, to efficiently find the 140 meter-sized objects that are nearly 50 times fainter compared to a one kilometer-sized object at the same distance and with the same reflectivity. Because all PHAs do eventually come very close to the Earth, the current ongoing surveys could complete the goal outlined in the 2005 NASA Authorization Act but it would likely take over a century to do so. We cannot afford to wait that long.

In the report to Congress requested by the 2005 NASA Authorization Act, several options were outlined, both ground-based and space-based, that could meet the goal of finding 90% of the PHAs larger than 140 meters by the end of 2020. For example, a one-meter aperture infrared telescope in a heliocentric orbit near Venus could do the job three years early. Within this report, NASA noted that it did not have the resources to carry out a survey option that would meet the 2020 deadline set by the 2005 Act and that, in an attempt to achieve the legislative goal by the end of 2020, it would seek to continue the

current survey programs and look for opportunities to use dual use telescope facilities and spacecraft along with partnering with other agencies as feasible.

At least two next-generation, ground-based, wide-field search telescope surveys are in development. The Panoramic Survey Telescope and Rapid Response System (PanSTARRS), under development at the University of Hawaii with Air Force funding, will have one of its four 1.8 meter telescopes operational in Hawaii in early 2008. If the planned, four telescope version of PanSTARRS is completed by 2010, it could help reach the goal by about 2040. Likewise the 8.4 meter aperture Large Synoptic Survey Telescope (LSST) that is under development with funding from NSF, DoE and other partners, could help reach the goal by about 2034 if it began operation in 2014. If we assume that both the PanSTARRS four telescope system and the LSST operate in their planned shared modes, which includes many observations unrelated to PHAs, then the goal could be reached by about 2026. The PHA discovery rate could be increased beyond the results shown in the NASA response to the 2005 Act if the observing time and sequences of PanSTARRS and LSST were optimized for PHA observations.

In terms of actual discoveries of new PHAs, there has been little success beyond the survey programs supported by NASA. However, the international community, including many sophisticated amateur astronomers, is very active in providing the follow-up observations necessary to secure an object's orbit once it has been found. The NEODyS program in Pisa Italy works closely with, but independent of, the NEO Program Office at JPL to compute impact probabilities for predicted Earth close approaches for at least 100 years into the future. It is also encouraging to note the activities of a NEO Action Team within the UN Committee on the Peaceful Uses of Outer Space (COPUOS) includes an effort to encourage more international efforts on the NEO issues.

**The importance of Radar Observations:** There are only two planetary radars in existence (and no alternatives) that can routinely observe close Earth approaching asteroids, and both of them are critically important for investigating the nature of these objects and for rapidly refining their trajectories. The 70-meter Goldstone antenna in California's Mojave desert is fully steerable, can track an asteroid and can cover large regions of sky while the larger 305-meter Arecibo antenna in Puerto Rico has twice the range but only observes within a 40-degree zone centered on the overhead position (20 degrees on either side of zenith). The capabilities of these two telescope complement one another and often a significantly better and longer set of observations can be achieved using both radars on a close approaching target asteroid.

Most positional data for PHA orbit determination and trajectory predictions are based upon optical, plane-of-sky observations. Because the radars provide line-of-sight velocity and range information accurate to about the 1 mm/s and 10 meter levels, these data when used in conjunction with the optical data provide a secure orbit and trajectory far more rapidly than if only optical data are available. With only a limited amount of optical data to work with, the orbit of a newly discovered PHA is often not accurate enough to immediately rule out a future Earth impact. However, with radar data in hand, the orbit of a newly discovered PHA can be quickly and more precisely determined, its

motion accurately projected far into the future and future impact possibilities can usually be quickly ruled out. Likewise, in the rare situation when an object is actually on an Earth threatening trajectory, radar observations will be critical in quickly identifying this case.

Unfortunately the Arecibo radar program is not funded by the NSF beyond FY2007 and the planetary science community is in danger of losing one of its instrumental crown jewels. As a measure of this radar facility's importance, note that 65% of all radar experiments to characterize near-Earth asteroids were performed at Arecibo, 47% of all binary near-Earth asteroids were discovered at Arecibo and 85% of the near-Earth asteroids with the critical astrometric radar data for orbit improvement have data from Arecibo. All of this was accomplished with only 5% of this instrument's time. The superior sensitivity of the giant Arecibo radar can determine the sizes, shapes, rotation characteristics, surface characteristics and binary nature for many PHAs. All of these physical characteristics are important criteria to understand before a deflection mission is considered. Radar observations are responsible for the best physical characterization of any PHA as large as a kilometer (i.e., the binary asteroid 1999 KW4). Radar observations reduce a PHA's orbit uncertainties quickly and dramatically so that future impact possibilities can be quickly knocked down thus reducing the odds that we will need to invest in a spacecraft investigation to characterize the PHA's nature in preparation for a precautionary deflection mission. Thus the relatively modest costs of maintaining the Arecibo radar in a robust state could prevent the future need for 100's of millions of dollars per case for spacecraft reconnaissance of an object to determine whether or not it is an actual threat.

**What Should be Done in the Event of an identified NEO Threat?** A number of existing technologies can deflect an Earth threatening asteroid – if there is time. The primary goal of the PHA survey programs is to discover them early and provide the necessary time. An asteroid that is predicted to hit Earth might require a change in its velocity of only 3 millimeters per second if this impulse were applied twenty years in advance of the impact. The key to a successful deflection is having sufficient time to carry it out, whether it is the slow, gentle drag of a gravity tractor or a more impulsive shove from an impacting spacecraft or explosive device. In either case, a verification process would be required to ensure the deflection maneuver was successful and to ensure the object's subsequent motion would not put it on yet another Earth impacting trajectory. While suitable deflection technologies exist, none of them can be effective if we are taken by surprise. It is the aggressive survey efforts and robust planetary radars that must ensure that the vast majority of potentially hazardous objects are discovered and tracked well in advance of any Earth threatening encounters. The first three steps in any asteroid mitigation process are: Find them early, find them early, and find them early!

## **Biographical Information**

### **Donald K. Yeomans**

At the Jet Propulsion Laboratory in Pasadena California, Donald K. Yeomans is a Senior Research Scientist, supervisor of the Solar System Dynamics Group, and manager of NASA's Near-Earth Object Program Office. His group is responsible for providing position predictions for the solar system's planets, natural satellites, comets and asteroids. For the comets and asteroids that can approach the Earth, his group monitors their motions and provides predictions and impact probabilities for future Earth encounters.

Dr. Yeomans was the Radio Science team chief for NASA's Near-Earth Asteroid Rendezvous (NEAR) mission. He is currently the NASA Project Scientist for the Joint Japanese and U.S. mission to land upon, and return a sample from, a near-Earth asteroid (Hayabusa) and he was a scientific investigator on NASA's Deep Impact mission that successfully impacted comet Tempel 1 in July 2005. He provided the accurate predictions that led to the recovery of comet Halley at Palomar Observatory on October 16, 1982 and allowed the discovery of 164 BC Babylonian observations of comet Halley on clay tablets in the British Museum.

He is a graduate of Middlebury College in Vermont and received his doctorate degree in astronomy from the University of Maryland in 1970. He has written numerous technical papers and four books on comets and asteroids. He has been awarded 15 significant achievement awards by NASA including an Exceptional Service Medal and a Space Act Award. To honor his work in planetary science, asteroid 2956 was renamed 2956 YEOMANS.