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 Committee, thank you for this opportunity to address you on the important issue of near-Earth objects and their potential threat to Earth.

I have been asked to address issues related to the use of radar systems to track and characterize near-Earth objects (NEOs) and, specifically, to address the role of the radar system on the giant Arecibo telescope in Puerto Rico in this activity and the current state of funding for this National Science Foundation facility. I will address these questions in turn.

- What role do Earth based radars play in the tracking and characterization of Near Earth Objects (NEOs)? What role, if any, do they play in providing information about specific hazardous objects?

Radar plays an important role in predicting the future orbits of NEOs and measuring many of their physical characteristics such as size, shape, rotation state and, in the case of binary objects, their mass and density. Radar can measure distances to NEOs to an accuracy of about 10 m (30 ft) and their line-of-sight velocity to an accuracy of about 1 mm per second (12 ft per hour), orders of magnitude better than the equivalent optical measurements. For potentially hazardous objects (PHOs), optical observations based on measuring their changing position on the sky over days or weeks in many instances cannot rule out a possible future impact with the Earth. To do so can require optical positional measurements spanning years or decades. For future searches, radar astrometry, the measurement of distance and line-of-sight velocity, can be used to help cull the number of PHOs – not all the newly detected NEOs will be observable with radar - so that we can concentrate on the few that really are potentially hazardous. For these objects, additional precision radar measurements are extremely important to assess the impact probability and the need to take action to mitigate the threat.

The more we know about NEOs in general and about specific ones that pose a threat to Earth, the easier it will be to design effective mitigation strategies. "Know your enemy" would seem to be good advice in this instance. NEOs form a very diverse population encompassing a large range of sizes, shapes, rotation states, densities, internal structure and binary nature. While a very small number of NEOs have been visited by spacecraft, radar provides by far the best means to survey these characteristics for a large number of objects. Knowing the range of characteristics facilitates the design of effective mitigation techniques that can be applied to an object with any of these characteristics. For an object that we know poses a direct threat to Earth, radar can provide vital input to mitigation planning including planning for any precursor space mission.

Over the past few years, the accuracy of the Earth impact prediction based on precision radar astrometry for a few PHOs has been limited not by the accuracy of the radar measurements but by the inability to accurately model all of the very small forces on these objects in addition to that due to the Sun's gravity. One of these forces, the Yarkovsky effect, is related to sunlight absorbed by the body and its re-emission as heat. Precision radar astrometry over several years of a small asteroid, Golevka, demonstrated in 2003 that this effect can modify the orbits of small asteroids over very long periods of time. This has revolutionized our understanding of how small asteroids in the main asteroid belt between Mars and Jupiter are transported into the inner solar system to become NEOs and, some, PHOs. This new understanding resulting from a basic science driven project will also help in refining PHO Earth impact probabilities for the few objects that may be of real concern.

- What role has the Arecibo Observatory played in surveying NEOs and what are the impacts to the NEO program should Arecibo be decommissioned?

The radar system on the NSF's Arecibo Telescope in Puerto Rico is one of only two very high powered radars in the world that are used for studying solar system bodies including NEOs. The other one is on NASA's Deep Space Network 70 m antenna at Goldstone in California's Mojave desert. With its 300 m (1,000 ft) diameter telescope and radiated power of one megawatt, the Arecibo radar is over 20 times more sensitive than the one on the Goldstone antenna. However, because of its limited steerability, Arecibo can only observe about half the sky observable with the Goldstone antenna making the two systems very complementary.

Because of its greater sensitivity and availability, the Arecibo radar system has carried out 65% of all radar observations characterizing NEOs, 47% of the known binary NEOs were discovered with Arecibo (most of the rest were discovered with optical telescopes), and data from Arecibo was used for 85% of the NEOs for which precision radar distance and velocity astrometric measurements have been made for orbit determination.

If the Arecibo radar system is decommissioned it would leave the lower sensitivity radar system on the NASA 70 m Goldstone antenna as the only radar system in the world capable of precise astrometry of NEOs and measurements characterizing their physical properties. A tremendous amount of basic science related to NEOs and other solar system bodies would be lost and the highest sensitivity radar would no longer be available to provide precision astrometry and characterization data just as the NEO search programs are ramping to a new level. Given the pressures on the 70 m Goldstone antenna in carrying out its prime mission, its lower sensitivity and the large number of NEOs likely to be detected over the next decade or more, it seems unlikely that this system could come close to filling the void. Replacing the Arecibo telescope and radar system with a mission specific facility of equal sensitivity would cost several hundred million dollars. Given its contributions to the NEO program and other research areas in radio astronomy and ionospheric physics and the relatively small budget needed to keep it operating, closing Arecibo does not make sense. In the words of Bill H.R. 3737, recently submitted by

Congressman Fortuño on behalf of himself, Congressman Rohrabacher and other members of the House of Representatives, “The Arecibo Observatory is an invaluable and unique asset in warning and mitigating potential hazards posed by near-Earth objects”.

- Did the recent National Science Foundation (NSF) Senior Review of Arecibo evaluate the facility’s role in surveying NEOs and the impact of Arecibo’s potential decommissioning on the NEO survey program? If not, why not?

The National Astronomy and Ionosphere Center (NAIC), the formal name for the Arecibo Observatory located in Puerto Rico, is one of the four National Astronomy Centers plus the US component of the international Gemini observatory, funded through the Division of Astronomical Sciences at the NSF and is operated by Cornell University under a Cooperative Agreement with the NSF. NAIC is unique among the Centers in that it supports research in three diverse areas, radio astronomy, planetary radar astronomy including the study of NEOs, and ionospheric physics. The first two are supported through funding from the Division of Astronomical Sciences at the NSF while the ionospheric program, about 15% of the budget, is funded through the Division of Atmospheric Sciences at the NSF. NAIC has about 120 people working at the Arecibo Observatory in Puerto Rico. In addition to providing research facilities for its scientific user community, it operates a visitor center that attracts about 120,000 visitors a year most from Puerto Rico including about 25,000 school children.

In 2005-2006 the Division of Astronomical Sciences of the National Science Foundation (NSF) undertook a “Senior Review” to examine the balance of its investments in the various astronomical facilities that the Division supports. The review was motivated by a combination of the budget outlook at that time for the Foundation and the ambitions of the astronomical community to invest in new facilities to address fundamental questions as recommended in the previous Astronomy Decadal Survey and other reports such as “Connecting Quarks with the Cosmos”. The Senior Review committee submitted its report to the NSF in November, 2006.

The aims of the Senior Review were widely supported by the astronomical community and it is not my intention to criticize its major findings. However, its charge was to look at the “big picture” and in such a process small, high quality programs that are not central to the priorities of the committee or the NSF can end up becoming a casualty on the way to the main goal. Such seems to be the case for the planetary/NEO radar program at the Arecibo Observatory. During the review process, Cornell University and NAIC provided considerable input to the committee about the Observatory’s research programs including the planetary/NEO radar program. Many planetary astronomers, especially those interested in NEOs, wrote to the committee strongly supporting the Arecibo radar program. However, the Arecibo planetary/NEO radar program was essentially ignored in the committee’s report with the only explanation I have heard being that the program was too small in funding terms to be individually considered. There were no planetary astronomers on the committee.

I should emphasize that the Senior Review report did not recommend that the Arecibo planetary/NEO radar program be cancelled but that is likely to be the outcome of its budgetary recommendations vis-à-vis NAIC. It recommended that NAIC’s operating funds provided by the NSF Division of Astronomical Sciences, about 85% of its yearly budget with the rest coming from the NSF Division of Atmospheric Sciences, be reduced over the following three years from approximately $10.5M to $8M and then, in FY2011, be halved again to $4M. By early 2009 Cornell is required to have definite commitments from other entities for the additional operating funds needed to keep the observatory open. If it cannot get these commitments then, in the Senior Review report's words "The Senior Review recommends closure after 2011 if the necessary support is not forthcoming".

The planetary/NEO radar program is scheduled to continue in operation at a reduced level of activity through FY 2008 compared with its normal use of about 400 hours of telescope time per year. If the NSF implements the Senior Review's recommendations to reduce NAIC's budget for astronomical research to the $8M level, budgetary pressures and deferred maintenance are then likely to make termination of the radar/NEO program unavoidable unless additional funding is found. Since the planetary/NEO radar system has significant operational and maintenance costs associated with the transmitting system, terminating it is the only identifiable way to save about $1M in operating costs short of canceling the observatory's entire radio astronomy program. The NSF has said that they will not augment NAIC's budget to provide support for the planetary radar/NEO program and has indicated that this area of research should be supported by NASA. Until a few years ago, NASA did provide partial support for the Arecibo radar program. In the slightly longer term, if additional operating funds are not found well before the projected FY2011 NSF/AST reduction to $4M then the Arecibo Observatory will possibly be closed definitely terminating its contributions to the tracking and characterization of NEOs.

- What level of funding and technical support would be required to carry out the NEO-related activities of Arecibo, independent of any other astronomy-related activities? Will any upgrades to the facility or its instruments be required?

The current yearly cost for operating Arecibo's planetary radar system for about 400 hours a year is close to $1M. About 60% of this time is devoted to NEO research. This covers the cost of the operation and maintenance of the high powered transmitting capability plus several engineers and a small scientific staff. It does not cover major maintenance items for the transmitting system. It also does not cover the cost for the operation and maintenance of the telescope and the general support for grounds, buildings, etc needed to keep the observatory operating as a facility. Prorating these costs based on the observing hours used would raise the current costs of the planetary radar program to close to $2M/yr.

No study has yet been done of the precise role of the Arecibo radar and how many hours of NEO observations will be needed when the new, high sensitivity searches commence starting with PanSTARRS. This needs to be done. The demand for the use of the Arecibo radar will undoubtedly increase significantly but whether by a factor of two or five is uncertain. While maintaining the observatory's multi-disciplinary program, some increase in the use of the radar system for NEO observations can certainly be accommodated. A program using about 500 hours a year for NEO observations and, perhaps, 100 hours for radar studies of other solar system bodies would cost $2M to $3M including its share of general observatory support costs. The costs would prorate roughly with observing time.

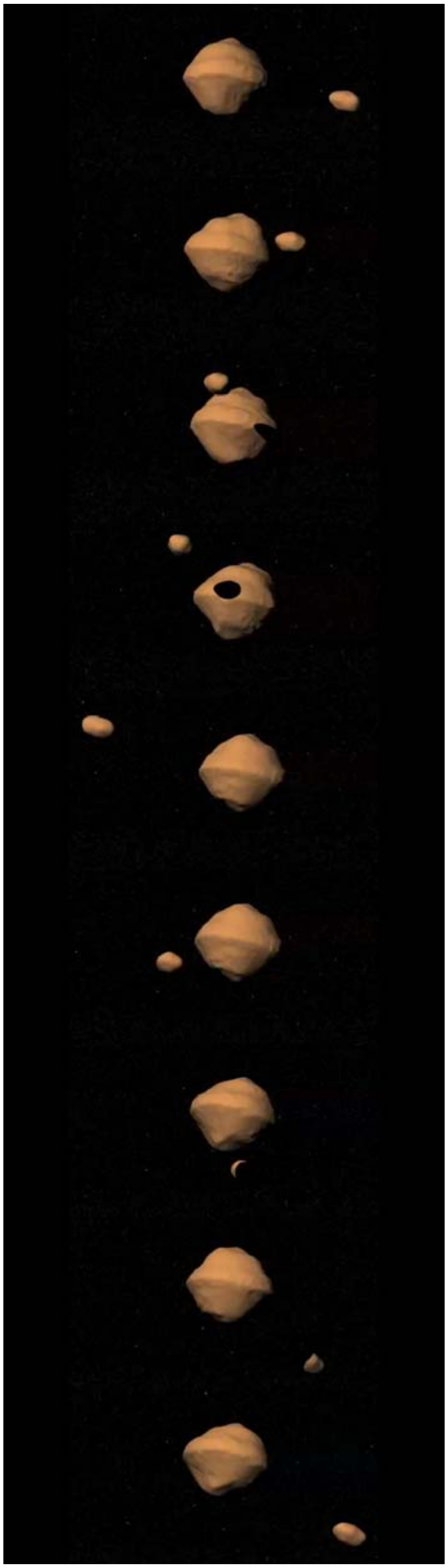
In answer to the question as to how much it would cost to support Arecibo for NEO activities independent of any other use of the telescope, the budget would need to be very roughly the same as the observatory's current budget, about $10M per year. Most of the operating costs of large telescopes are fixed costs related to maintenance, etc independent of the science mission. However, I want to emphasize that any NEO radar program is unlikely to utilize all, or even a majority, of the observing time available on the telescope.

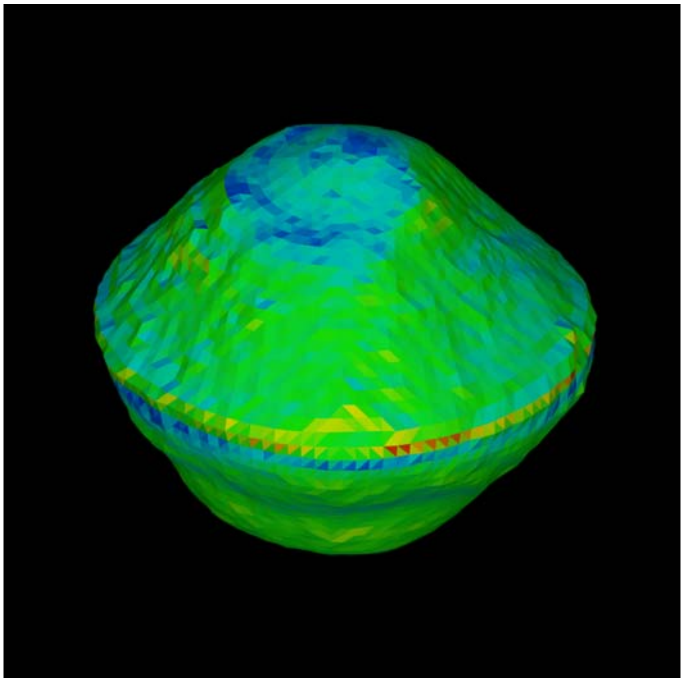
The Arecibo telescope and radar system underwent a major NSF and NASA funded upgrading about ten years ago. At this time some major components of the transmitting system need refurbishment or replacement and some of the data handling equipment used for the NEO program needs updating. Total costs of this are estimated to be about $2M.

- What are your perspectives on NASA's *Near-Earth Object Survey and Deflection Analysis of Alternatives* Report to Congress?

NASA's report was a comprehensive discussion of the issues related to the detection of 90% of all NEOs larger than 140 m by 2020, the requirement to determine their orbits, understand the broad characteristics of different classes of asteroids in order to be able to design mitigation strategies, and, of course, the range of possible mitigation strategies. Staying within my area of expertise, the report's discussion on the usefulness of determining orbits with radar versus with optical means and the best means to characterize these objects to, in the report's words, "inform mitigation" should be revisited. For orbit determination the issue is whether a relatively quick refinement of at least some percentage of the orbits of newly discovered PHOs is preferable to waiting the 10 to 20 years that optical means require for orbit determinations that will as stated in the report "nearly match the accuracy of radar-improved orbits".

The role of the radar systems in surveying the broad range of NEO types could also have been given more emphasis in the report. Radar is currently the only Earth or Earth-orbit based technique that has the resolution needed to provide information about a wide range of physical properties important to mitigation planning. The images below show the detailed shape model of the main component of the binary NEO 1999 KW4 and a simulation of the binary system, results obtained by Steven Ostro of JPL and colleagues from observations using the Arecibo and Goldstone radars. The work was described in the cover article of Science magazine last November. We now know KW4's size, about 1.5 km (1 mile) for the main body, shape, rotation rate, mass, density and that it is a binary object. The low density of the main body, about twice that of water, tells us that it is rubble pile rather than a single large "rock". This is all information that is critical to "informing mitigation".





Binary Near-Earth Asteroid 1999 KW4

Top image: A detailed shape model derived from Arecibo and Goldstone radar observations of the 1.5 km (1 mile) diameter main body of the binary NEO 1999 KW4. Its low density, about twice that of water, indicates that it is an unconsolidated “rubble pile” kept together by gravity. Color indicates the apparent slope of the surface.

Left image: A computer generated simulation of the ~0.5 km (0.3 mile) “moon” in its 17 hour orbit about the main body. Its orbital distance from the center of the main body is about 2.5 km. The black areas on the main body in the 3rd and 4th images are the shadow of the moon in this simulation.

See Science magazine and its cover image from 24 November, 2006 for a detailed description of this work. Images courtesy of S. Ostro (JPL) and D. Scheeres (University of Michigan).