House of Representatives

Committee on Science and Technology

Subcommittee on Space and Aeronautics

November 8, 2007

Hearings on

Near-Earth Objects (NEOs) – Status of the Survey Program and Review of NASA's Report to Congress

J. Anthony Tyson

Mr. Chairman and Members of the Committee. It is an honor to be asked to testify before you today on this important subject. By way of identification, I am an astrophysicist and professor of physics at the University of California, Davis, and director of the Large Synoptic Survey Telescope (LSST) project; before coming to UC Davis four years ago I did research and development at Bell Labs for 34 years.

The house committee on science has been a leader on a bi-partisan basis for over two decades in focusing attention on the need to detect, characterize, and catalog near- Earth asteroids. The passage of the "George E. Brown Jr. Near Earth Object Survey Act" was a landmark piece of legislation that sets a goal of cataloging 90% of NEOs of 140 meters in diameter and larger within 15 years. The Committee is properly looking at the existing and future capabilities for carrying out this goal and expanding the existing Spaceguard program. LSST adopted the goal of surveying NEOs at the outset as one of its major science capabilities.

Until recently, the discussion of risk associated with an impact of a NEO has been statistical; what is the probability? This is similar to considerations of risk in many other areas such as weather and traffic accidents. What if it were feasible to deploy a system that would alert me of an impending traffic accident well in advance? That would change the very nature of that risk from a probabilistic worry to a deterministic actionable situation. The ability to detect virtually every potentially hazardous Near-Earth object and determine its orbit with precision transforms that statistical threat into a deterministic prediction. We face many threats, and virtually all of them are either so complex or unpredictable that they are treated probabilistically even though the social and

financial consequences are legion. With a comparatively small investment the NEO risk can be transformed from a probabilistic one to a deterministic one, enabling mitigation.

The First Job: Finding the NEOs

Ground-based optical surveys are the most efficient tool for comprehensive NEO detection, determination of their orbits and subsequent tracking. (Radar also plays an important role once a threatening NEO has been found, in refining its orbit when the NEO is near.) The first job is to find the NEOs which are potentially hazardous (so-called Potentially Hazardous Asteroids) from among the swarm of ten million other asteroids. A survey capable of extending these tasks to NEOs with diameters as small as 140 m, as mandated by Congress, requires a large telescope, a large camera, and a sophisticated data acquisition, processing and dissemination system. The Congressional mandate drives the requirement for an 8-meter class telescope with a 3000 Megapixel camera and a sophisticated and robust data processing system. These requirements are met by the LSST.

Why is a large telescope required? A typical 140-meter NEO appears very faint (visual magnitude of 25). Multiple NEO detections in a single night are required to estimate its motion, so that its future or past detections can be linked together. This linkage has to be done exceedingly robustly because the near-Earth objects will be outnumbered nearly a thousand to one by main-belt asteroids (between Mars and Jupiter) which present no threat to Earth. By reliably linking detections on multiple nights, the NEO's orbit can be reconstructed and used to compute its impact probability with Earth. Despite their name, NEOs are typically found far from Earth. In principle, very faint objects can be detected using long exposures, but for objects moving as fast as typical NEOs, the so-called trailing losses limit the exposure time to about 30 seconds. In order to detect 140-meter NEOs in 30 seconds, an 8-meter class telescope is required.

Why is a large camera required? The need for a very large field of view comes from the requirement that the whole observable sky should be observed at least every four to five nights. For comparison, we need a field of view thousands of times larger than the Hubble Space Telescope's Advanced Camera for Surveys. With its 10 square degree field of view, LSST will be able to reach the mandated high NEO completeness.

Finding Near-Earth Objects with Ground-based Surveys

Ground-based optical surveys are a very cost effective tool for comprehensive NEO detection, determination of orbits, and subsequent tracking. A survey capable of extending these tasks to NEOs with diameters as small as 140 m, as mandated by Congress, drives the requirement for a large telescope, a large camera, and a sophisticated data acquisition, processing and dissemination system.

To find a significant fraction of the faint NEOs one must essentially make a movie of the deep sky. Each faint asteroid must be captured in many separate exposures in order for computers to distinguish it from the numerous other asteroids and then piece together its orbit. A large area of the sky (ideally all the sky visible from some location on Earth, at least 20,000 square degrees) must be surveyed rapidly and deeply in order to survey a large volume for these faint asteroids. The ability of a telescope and camera to take rapid deep repeated images of the entire sky is proportional its "throughput." Throughput (sometimes called etendue) is simply the product of the telescope light collection area (units: square meters) times the camera field of view in a single snapshot (units: square degrees.) Thus throughput of a survey facility is measured in units of square meters square degrees. The throughput of LSST is 320 square meters square degrees. High throughput is a necessary condition for such a facility to carry out its mission, but not a sufficient condition: one must also arrange to have high observing efficiency (access to the sky) and highly efficient optics and imaging detectors in the camera, as well as superb image quality.

For an efficient NEO survey, the whole observable sky should be observed at least every four to five nights, with multiple observations per night. In order to do so with exposure time of about 30 seconds per observation, a 10 square degree large field of view is required. Such a large field of view, with pixel size sufficiently small to fully sample the image at a good observing site, implies a multi-billion pixel camera. Indeed, at the time of its completion, the 3.2 billion pixel LSST camera will be the largest astronomical camera in the world.

With a 3.2 billion pixel camera obtaining images every 15 seconds (individual 30 second exposures are split into two 15 second exposures for technical reasons), the data rate will be about 20 thousand gigabytes per night. Not only is this a huge data rate, but the data have to be processed and disseminated in real time, and with exquisite accuracy. It is estimated that the LSST data system will incorporate several million lines of state-of-the-art custom computer code.

State of the LSST project

The Large Synoptic Survey Telescope (LSST) is currently by far the most ambitious proposed survey of the sky. With initial funding from the US National Science Foundation (NSF), Department of Energy (DOE) laboratories and private sponsors, the design and development efforts are well underway at many institutions, including top universities and leading national laboratories. The main science themes that drive the LSST system design are Dark Energy and Dark Matter, the Solar System Inventory, Transient Optical Sky and the Milky Way Mapping. It is this diverse array of science goals that has generated the widespread excitement of scientists ranging from high-energy physicists to astronomers and planetary scientists, and earned LSST the endorsement of a number of committees commissioned by the National Academy of Sciences.

Fortunately, the same hardware and software requirements are driven by science unrelated to NEOs: LSST reaches the threshold where different science drivers and different agencies (NSF, DOE and NASA) can work together to efficiently achieve seemingly disjoint, but deeply connected, goals. Because of this synergy the Congressional mandate can be reached at only a fraction of the cost of a mission dedicated exclusively to NEO search.

The scientific priority for constructing a large aperture ground based survey telescope was recommended in the astronomy and astrophysics Decadal Survey 2000 report entitled Astronomy and Astrophysics in the New Millennium. Since then, LSST has reached a high state of design maturity. LSST has recently passed the NSF Conceptual Design Review for construction, which puts it on track for transition to Readiness in spring 2008. LSST is a public-private project. To date $44M in private funding has been raised. Twenty two institutions have joined the effort and have contributed significant in-kind technical labor. LSST R&D continues for another 3 years under NSF support along with in-kind contributions. The project is on track for first light in 2014. It is proposed that the DOE (because of the importance of LSST for addressing the mystery of dark energy) support the $80M cost of constructing the camera. Foreign support now appears likely, and this in-kind would offset the camera cost.

Method of Study: the LSST Operations Simulator

The LSST Operations Simulator was developed to be able to do just the sort of assessment described in this document. It contains detailed models of site conditions, hardware and software performance, and an algorithm for scheduling observations which will, eventually, drive the robotic LSST observatory. The resulting sky coverage for the LSST baseline cadence is shown in Figure 1.

For the currently planned LSST baseline cadence, objects counted as cataloged are observed on 20 different nights on average. A more stringent requirement could decrease the completeness by up to 3%. The completeness is also a function of the assumed size distribution: the flatter the distribution, the higher the completeness. If the latest results for the NEO size distribution by A. Harris are taken into account, the completeness increases by 1-2%. Due to these issues, the completeness estimates have a systematic uncertainty of 2%. Our analysis assumes that no NEOs are known prior to LSST. Current surveys make a negligible contribution to the 90% completeness for NEOs of 140m and up.

The NEO survey completeness achievable with LSST

The LSST system is the only proposed astronomical facility that can detect 140-meter objects in the main asteroid belt in less than a minute. The LSST system will be sited at Cerro Pachon in northern Chile, with first light scheduled for 2014. In a continuous observing campaign, LSST will cover the entire available sky every four nights, with at least two observations of an NEO per night. Over the baseline survey lifetime of 10 years, each sky location would be observed over 800 times. Two NEO detections in a single night are required to estimate its motion, so that its future or past detections can be linked together. This linkage has to be done exceedingly robustly because the near-Earth objects will be outnumbered a hundred to one by main-belt asteroids which present no threat to Earth. By reliably linking detections on multiple nights, the NEO's orbit can be reconstructed and used to compute its impact probability with Earth.

The currently planned LSST baseline observing cadence on the sky, described in the Major Research Equipment and Facilities Construction proposal submitted to NSF, is simultaneously optimized for all four main science drivers: Characterizing Dark Energy and Dark Matter, the Solar System Inventory, Transient Optical Sky, and the Milky Way Mapping (see Figure 1). Computer simulations of LSST observing show that the data stream resulting from this baseline cadence on the sky is capable of providing orbits for 82% of Potentially Hazardous Asteroids (PHA) larger than 140 meters after 10 years of operations. The completeness curve as a function of time since the start of the survey is shown in Figure 2 (second curve from top). This baseline cadence spends 5% of the total observing time on NEO-optimized observations in the north region of the ecliptic (plane of the solar system.)

Various adjustments to this baseline cadence can boost the completeness for 140m and larger PHAs to 90%. Based on about 100 different simulations, we find that such adjustments to the baseline cadence or filter choices can have unacceptably large impact on other science programs, if the 90% completeness is

to be reached within 10 years from the beginning of the survey. However, with a minor adjustment of the baseline cadence and additional specialized observing for NEOs, this completeness level can be reached with a 12-year long survey, and with a negligible effect on the rest of science goals.

These specialized observations would be of limited use to other science programs, and they require 15% of the observing time. The dependence of completeness for 140m and larger objects on time is shown in Figure 2.   For LSST, Figure 2 shows the baseline survey and the special NEO-optimized survey. In addition, we also show completeness curves for the same observing cadence and under the same assumptions regarding seeing and efficiency for smaller versions of LSST of less throughput.   The lowest curve (black line) in Figure 2 shows the completeness for current NEO assets (ca. 2014-) for comparison.

Conclusions

The ability of LSST to reach the mandated 90% completeness for 140m and larger PHAs in 10 years by the so-called "dedicated" option described in the 2007 NASA NEO report is supported by our detailed and realistic simulations. An important additional insight from these simulations is that we can deliver the performance of a "dedicated" system by spending 85% of the total observing time on a general survey useful for all LSST science programs, and by specializing only about 15% of the total observing time for NEO surveying. If such an NEO-optimized program is executed for 12 years, the 90% completeness for 140m and larger PHAs can be reached without a significant negative impact on other science programs.

The current cost estimate for LSST in 2006 dollars is $389M for construction and $37M per year for operations. For a 12-year long survey, 15% of the total cost is $125M. Thus, we could deliver the performance of a full NEO-dedicated LSST to NASA at a small fraction of the total cost to build and operate such a system. This cost is equivalent to 30% of operations, which would commence in 2014. To assure LSST keeps on schedule, about $5M should be spent on optimized NEO orbit software pipeline development in the last phase of R&D and the construction phase, 2009-2014.

Executive Summary

In December 2005 Congress directed NASA to implement a near-Earth object (NEO) survey that would catalog 90% of NEOs larger than 140 meters in 15 years. In order to fulfill the Congressional mandate using a ground-based facility, an 8-meter class telescope equipped with a 3200 Megapixel camera, and a sophisticated and robust data processing system are required. These criteria are met by the Large Synoptic Survey Telescope (LSST). We have carried out over 100 simulations of the LSST operations for a variety of NEO-optimized scenarios. The planned LSST baseline survey cadence on the sky, simultaneously optimized for all main science drivers, is capable of providing orbits for 82% of PHAs larger than 140 meters after 10 years of operation, and is 90% complete for objects larger than 230 meters. This baseline cadence assumes that 5% of the total observing time is spent on NEO-specialized observing. This is what is currently planned. By increasing this fraction to 15% and by running the survey longer, the Congressional mandate of 90% completeness for NEOs of 140m and greater size can be fulfilled after 12 years of operation, with 60% completeness level reached after only 3 years.

Note that by operating LSST in this special NEO-enhanced mode we would have the performance equivalent of an LSST fully dedicated to NEO surveying. By supporting only 15% of the total cost, NASA would be essentially getting a NEO-dedicated LSST. This is a key new insight relative to the costing model in the 2007 NASA NEO report to Congress.
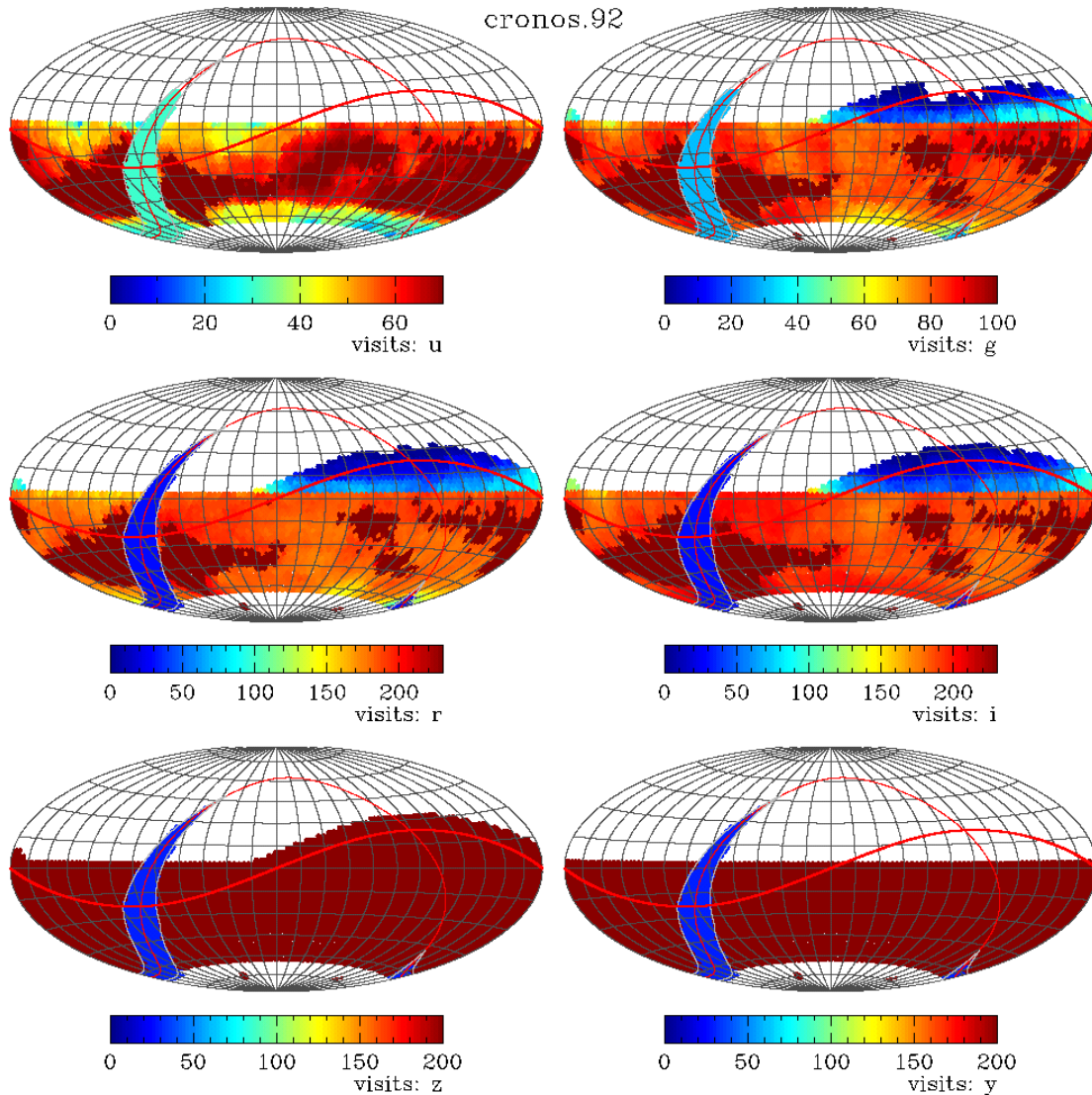
Figure 1. The result of computer simulations of planned LSST operations. Plots of LSST's coverage of the sky are shown for each of the 6 colors (wavelength bands from the ultraviolet to the near infrared), denoted ugrizy. These simulations are fully realistic in that they incorporate real weather data from the LSST site and detailed LSST system behavior. The number of visits per field in each filter for the simulated 10-year long baseline survey is shown. The blue area seen in the upper right part of the griz panels represents observations optimized for NEO survey in the planned baseline survey. However, all the displayed observations contribute to the Potentially Hazardous Asteroid completeness. Although the baseline survey achieves a completeness of 82% after 10 years, additional NEO-dedicated observing can achieve 90% in 12 years as shown in Figure 2.

Completeness Fraction for NEOs, 140 m or Larger, from Ground Based Facilities of Various Throughput*

Survey facility (Throughput*)
- LSST NEO optimized (320)
- LSST (320)
- (70) max. possible
- (16) max. possible
- Existing NEO Assets

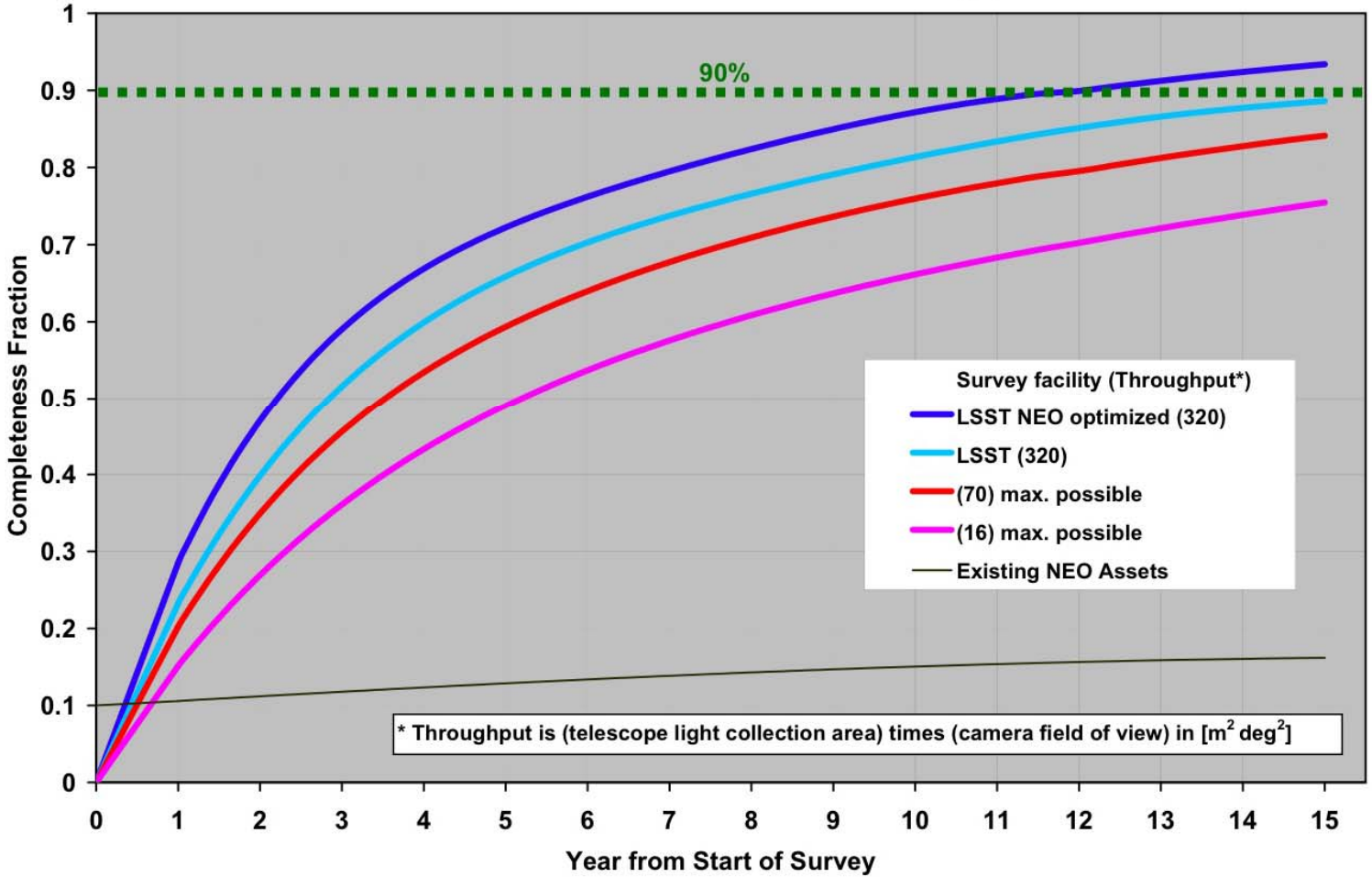* Throughput is (telescope light collection area) times (camera field of view) in [m² deg²]

Figure 2. The completeness of several NEO surveys, based on LSST baseline cadence on the sky, is shown vs time from the start of the survey. The top two curves, with 15% and 5%, correspond to the LSST special NEO-optimized and the baseline LSST plan. The other curves represent the maximum possible completeness for less capable systems with smaller throughput. The top curve, based on 15% of the observing time spent in an NEO optimized mode, reaches the Congressional goal of 90% completeness for PHAs larger than 140m after 12 years of surveying. Given the timeline for agency approval of construction funding, it is likely that the LSST will have first light in 2014 and the sky survey will begin in 2015. With the survey start in 2015, the completeness for 140m and larger objects achieved in 2020 would be 70%, with 90% completeness for 350m and larger objects. Facilities with throughput smaller than LSST's 320 square meters square degrees have corresponding less completeness as shown in the lower curves.